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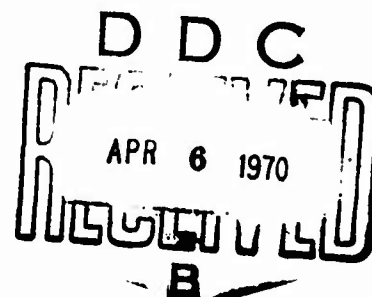
REPORT NO. 249

DEVELOPMENT TESTS OF SCREENED ARMOR PLATE

by

J. Leeder

August 1941



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DEVELOPMENT TESTS OF SCREENED ARMOR PLATE

Abstract

The results obtained in the first Development Test of Screened Armor Plate at A. P. G., Firing Record 20774, A310 were analyzed. The use of tipping screens was shown to have produced extraordinary increases in protective efficiency of both face hardened and homogeneous armor plate, particularly for the latter type. In view of the somewhat inappropriate location of the yaw cards, direct correlation of striking yaw and armor plate penetration was not possible. For the caliber 50 firings, however, it appears that striking yaws of at least 30° - 40° must be attained for the desired large increases in armor plate resistance, and that the exact striking yaw when greater than this approximation is of secondary importance.

A comparison was made of the ballistic performance of the screened homogeneous armor plate and homogeneous armor plate at high obliquities. In general there were no large differences discernible in so far as the limiting velocities were concerned. The basic cause of the great increase in protective efficiency of the armor plate when employed with tipping screens, or at obliquities is considered to be the breaking up of the small arms bullet cores.

A general discussion of some aspects of screened armor plate is given and recommendations made for an extensive program involving both the armor plate and tipping screen phases of the problem.

INTRODUCTION

Recent investigations of light armor protection have given special attention to the tipping or tumbling of bullets after striking thin shields, for the most part of duraluminum, placed at an angle of obliquity to the bullet trajectory.^{1,2}

More recently at Aberdeen Proving Ground, an attack on the general problem of the influence of shielding members was commenced with a fundamental series of experiments on the tumbling effect of different thicknesses of duraluminum and steel shields at obliquities ranging from 0° - 60°. The effect of incident yaw on the subsequent tumbling effect of the screen was investigated by spark photography. The detailed results and analysis are presented in Ballistic Research Laboratory Report No. 220. Specific points pertinent to the following report are referred to in appropriate instances.

Based on the results of this fundamental investigation a series of tests of screened armor plate combinations were undertaken, the results being reported in Development Test of Screened Armor Plate, Firing Record No. 20774, A310, dates of test, 12-27-40 and 1-31-41. A report of Capt. Atkins dated March 20, 1941, containing in part a preliminary analysis by the Ballistic Research Laboratory, was appended.

In view of the practical importance of the information contained within this Firing Record, an attempt is made in this report to present a more extensive analysis and to revise the preliminary report presented to the Proof Department which was based only on incomplete information.

¹Naval Research Laboratory Report, No. O-1540, Fifth Partial Report on Light Armor Plate "The Effect of Yaw upon Penetration; the Effect upon Bullets of Penetrating very thin Duraluminum Sheets; and the Use of Shielding Structures in the Form of Gratings". Dates of Tests, June, 1938 - June, 1939.

²Naval Research Laboratory Report, No. O-1600, Seventh Partial Report on Light Armor Plate. "Light Armor at High Obliquities, Oblique Shields and the Use of Duraluminum for Armor Protection." Date, March 21, 1941.

SECTION I

ANALYSIS OF FIRING RECORD NO. 20774, A310. DEVELOPMENT TEST OF SCREENED ARMOR PLATE

1. Tipping Screen Arrangements and Yaw Measurements

According to the Firing Record, shields of 1/8" duraluminum were mounted 4' and 5.5' in front of homogeneous or face hardened armor plate and at an angle of 60° to the line of fire for all but one test, the armor plate proper being always at normal obliquity.

The tumbling action of any screen was measured by sets of yaw cards placed at 21" and 46" in front of the armor plate. In many cases only one yaw card placed at about 21" in front of the armor plate was employed. The disposition of the component parts is shown in Fig. 1 with the notation applied to refer to the distances involved. The positions of the yaw cards and armor plate are indicated on Plots No. 1 and No. 2.

2. Tabulation of Armor Plate Results and Yaw Data

The information in the Firing Record round by round for those tests where tipping screens were utilized and yaw cards were available were relisted with the yaw card data in Table I. The sequence of presentation of data and notation follows that of the Firing Record. A more detailed characterization of the armor plates involved, or reference thereto, is given in the notes of Tables III.

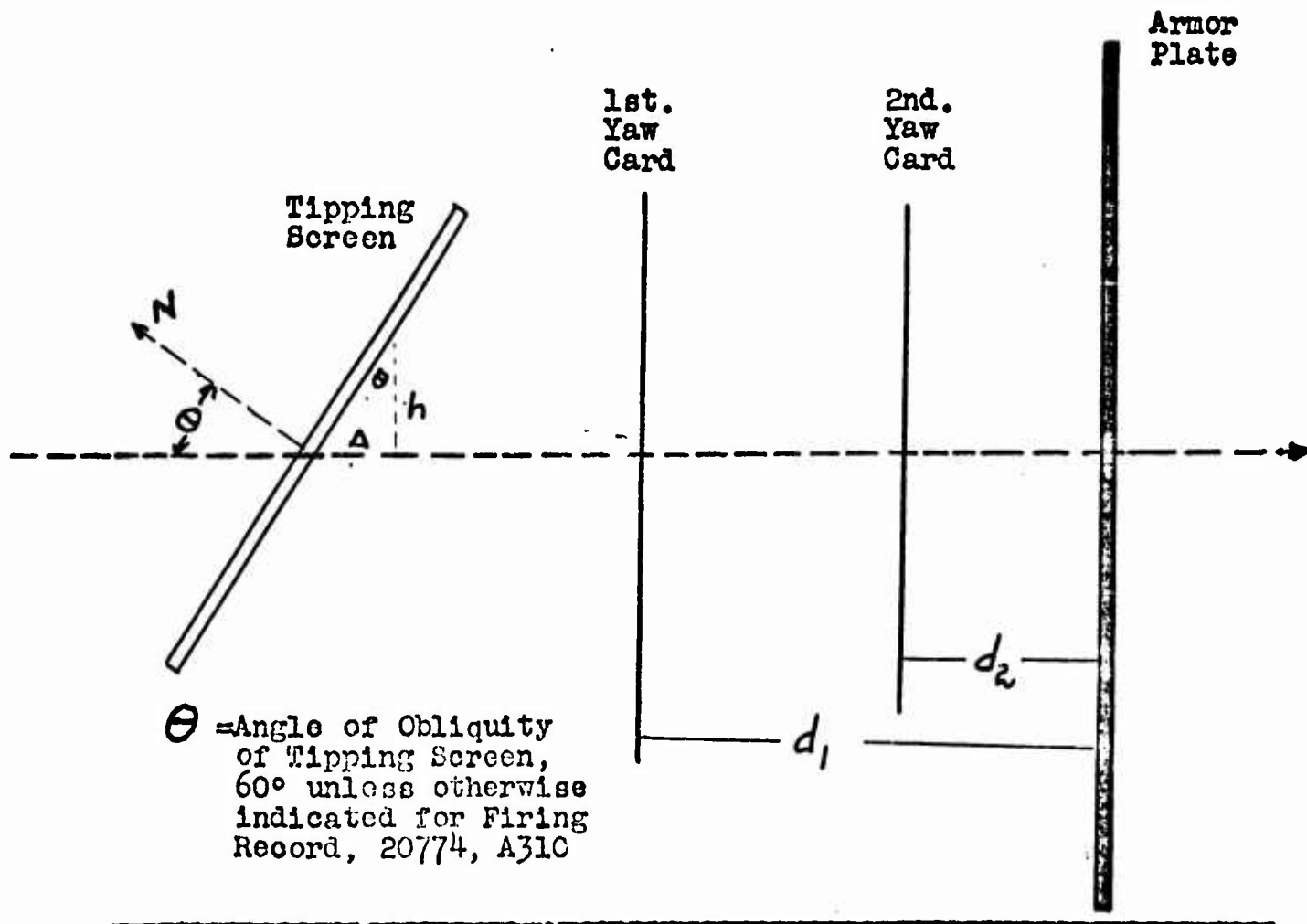
The limit velocity for each armor plate-tipping screen combination, with the ave age measured yaws and the range in yaw of all firing defining the ballistic limit are given in Table II. A few comments are also presented with a rough qualitative estimation of the striking yaws of the caliber .50 bullets.

3. Frequency Distribution of Measured Yaws

The measured yaws in Table I were rounded off to the nearest 5° and the frequency distribution of the yaw values for the caliber .30 and .50 bullets at the various given distances (Fig. 1) beyond the 1/8" dural tipping screen at 60° indicated in Plots No. 3, 4, and 5. From these plots, as well as from Tables I and II, the large variations in measured yaws at the different distances indicate departures from the experimental conditions under which the prior results for Plots No. 1 and 2 from B.R.L. Report No. 220 were obtained. The writer believes that possibly the main difference in the experimental conditions lay in the

Fig. 1

Disposition of Component Parts
of Screened Armor Plate



For $\theta = 60^\circ$ for tipping screen, for a displacement of trajectory,
 $\Delta = 1.73$ inches per inch of h , vertical displacement,
 where Δ is change in distance between armor plate and tipping screen.

determination of the screen to plate distance. This distance was accurately measured along the trajectory of the bullet as in Fig. 1, in the case of the B.R.L. results (through moving the screen after each impact), whereas in this Firing Record the distance between center points of screen and plate was designated as the screen to plate distance. The tipping screen and armor plate remained fixed, the trajectories of the bullets being varied to place the shots on the plate as in the usual routine test procedure. From Fig. 1 it readily follows that with the tipping screens placed at 60° from the vertical as shown, the screen to plate distance will change approximately 1.7" per inch of vertical displacement of the trajectory of the bullet. Hence for shots roughly scattered over a circle at least 1 ft. in diameter, the resulting changes in screen to plate distance would represent a large fraction of the length of cycle for the cal. .30 bullet (or rather core, as to be mentioned later) as is evident from Plot 1 and an appreciable part even of the longer cycle of the caliber .50 bullet (Plot 2).

4. Effect of Screen on Bullet

Apart from the tumbling action imparted by the screen, for those tests recorded in Table I wherein $1/8"$ dural screens at 60° were employed, the jackets of the caliber .30 bullets were almost invariably stripped from the core, whereas for the cal. .50 bullets the jackets were only partially stripped at the nose. In a small percentage of the cases, the cal. .30 core was broken by the screen.

A greater scattering in values of the yaw and yaw period of the caliber .30 bullets is to be expected as a consequence of the necessarily irregular nature of the stripping action. On plot No. 1 the behaviour of the cal. .30 bullets with stripped jackets as indicated is to be noted in contrast with that for the intact bullet.

5. Estimation of Striking Yaw

The fact that the nearest yaw card to the armor plate was 21" did not permit a quantitative evaluation of the striking yaw. From the measured yaws of the two sets of yaw cards for the caliber .50 firings and a rough correlation with the regular Yaw vs. Distance Curves of Plot 2, and indication of the minimum striking yaws at least could be obtained in most cases (Table II). The greater irregularity in measured yaw values for the caliber .30 bullets, (partial explanations of which have been given in the foregoing) the relatively short length of cycle for the stripped core, and the use of only one yaw card in many instances, - all combined to make even a qualitative estimate of the striking yaw dubious. Therefore no

estimate of the striking yaws of the caliber .30 bullets was made. For the caliber .50 bullets, the armor plate was placed at roughly the optimum distance behind the screen corresponding to the maximum of the yaw cycle, plot 2; the measured yaws for the individual firings in Tables I and average values for each series, Table II, increased with distance beyond the screen, and therefore indicated that the maximum of the yaw cycle had not been obtained, the yaw being either on the ascending branch of the curve, or at the maximum. For the greater portion, the striking yaws of the caliber .50 bullets were estimated to be larger than 40° at least, and for all to be greater than 20° - 30°.

6. Uniqueness of Ballistic Limit

Viewed as a whole, from the entire series of firings relatively consistent results were secured enabling the determination of an apparently true, uniquely defined ballistic limit. In Table II, one anomalous or irregular result with the cal. .30 bullets was noted. This consisted in a bullet with a large yaw as measured on the 2nd yaw card giving a greater penetration than one with a smaller yaw.

7. Quantitative Analysis of Ballistic Limits

The ballistic limits for the armor plates tested, with and without tipping screens, for the various models and calibers of bullets employed are presented in Tables III-a and III-b together with notations as to the individual plates. In a few instances some minor changes were made in the limiting velocities as reported in the Firing Record upon consideration of the individual data.

A quantitative means of measuring armor plate efficiency, and of evaluation for comparative purposes is afforded by the Navy "F" formula defined as follows for small arms bullets and normal impact:

$$F = \frac{w^{1/2} v}{2.013 t^{1/2} d}$$

where

w = weight of core in grains

d = diameter of core, inches

t = thickness of plate, inches

v = limit velocity, f/s

All calculations in this report are based on the core of the bullets. Therefore for a given projectile and thickness of plate, the energy required for complete penetration is proportional to F^2 .

To obtain an appropriate means of comparing the efficiency of the screened armor plate combinations with that of unscreened plate, the projected weight of the tipping screen on unit area normal to the bullet trajectory was determined and evaluated in terms of equivalent thickness of steel plate, this equivalent screen thickness plus the thickness of the armor plate (which was always normal) being designated in Tables III, IV, and V as "Total Equivalent Projected Thickness" measured in inches. For these reductions the densities of the plates were taken as:

<u>Material</u>	<u>Density</u> <u>(lb. per cu. in)</u>
Armor Plate	.283
Duraluminum	.101

Calculations of F for the screened plate combinations based on these equivalent projected thickness values are given in Table III. To obtain the prevalent trend of the detailed results, the limiting velocities and F values in Table III were averaged with respect to caliber of bullet and type of screened plate combination, differences due to model of bullet and individual plates being a second order effect. The results are given in Table IV with the probable errors in the average values of the limiting velocities and F values thus found from the individual determinations. A very large probable error was only found in the caliber .30 firings at the 1/4" face hardened plate 4 ft. in back of the tipping screen at 60°. The F values are graphically portrayed for the caliber .50 bullets for both homogeneous and face hardened armor plate in Plot No. 6.

From these results, the indication is that a combination of homogeneous plate and tipping screen is superior to a similar combination of face hardened plate and tipping screen. A strict comparison is possible for those combinations having 1/4" face hardened and homogeneous plates respectively. The results for these cases as taken from Table IV are tabulated below.

Comparison of Screened Armor Plate Having 1/4" Face Hardened
and Homogeneous Plate Respectively

Type Armor Plate	Average Limit Velocity	*P.E.	Average F.	*P.E.	No. of Determ.
<u>Tipping Screen of 1/8" Dural, 4 ft. in Front of Plate at 60° Angle. Caliber .30 Bullets</u>					
Face Hardened	2689	9	84700	900	2
Homogeneous	2767	406	87200	14000	2

<u>Tipping Screen of 1/8" Dural, 5-1/2 ft. in Front of Plate at 60° Angle. Caliber .50 Bullets</u>					
Face Hardened	1465	25	59100	1080	2
Homogeneous	1573		63500		1

* Probable error of average.

For the caliber .30 tests the large probable error in the results for the homogeneous plate makes the comparative evaluation difficult. The tipping screen combination having the homogeneous plate showed with the caliber .50 bullets an F value 7-1/2% greater than that for the combination with the face hardened plate. This figure corresponds to 15% greater energy in the limiting velocity. That the relative advantages to be gained by the use of tipping screens are substantially less for face hardened plate than for homogeneous is brought out in the following analysis.

To secure an estimate of the increase in armor efficiency attributable to the use of the tipping screens, the given screened plate combinations were compared to the straight armor plate (face hardened or homogeneous) at normal obliquity on the basis of (1) the weight of armor plate having the same ballistic limit i.e., providing the same protection

and (2) on the basis of increased protection calculated from the energies corresponding to the limiting velocities of armor plate having the same thickness (and hence weight per unit area) as the equivalent projected thickness of the screened plate. The comparative results determined from the average performance data of the screened plates from Tables IV are given in Tables V. For the calculations involved, it was necessary to have a quantitative means of determining for the caliber .30 and .50 bullets the limiting velocities of face hardened and homogeneous plate of any thickness and "quality" homologous to that of the given armor plate component of the screened plate. An accurate representation of the behaviour of Carnegie Illinois homogeneous plate similar in "quality" to that employed in the screened armor plate tests was available from prior Firing Records (notes in Table III-b) and is summarized in Plots No. 7 and 8.

A similar direct evaluation was not possible for the face hardened plate. Since no formulae to the writer's knowledge were adequate in predicting the ballistic performance of face hardened armor plate from an observed value for one thickness, the assumed constancy of F not being valid for the results obtained at A.P.G., the average performance results for acceptable plate from recent A.P.G. Partial Reports and Firing Records of Armor Plate were utilized to determine the performance curves in Plots No. 9 and 10.

For the caliber .30 tests, the average performance curve in Plot No. 9 was shifted vertically a small distance (corresponding to 30 f/s in limit velocity) as indicated to pass through the average ballistic limit of the 1/4" face hardened plates used for the screened plates. No values were available of limiting velocities for caliber .50 bullets of face hardened plate between 1/4" and 3/8" in thickness. Hence the curve in Plot No. 10 for the thicknesses within this range is very dubious as are the calculations involving interpolations in this region.

From Table V, the greater relative increase in performance of homogeneous plate as compared with face hardened due to the use of tipping screens is clear. Thus the weight savings for the face hardened plate combinations (with the exception of the combination with 1/4" plate for the caliber .50 firings) are in the neighborhood of 25% while for the homogeneous plate series the weight savings are in the vicinity of 50%. Similarly, for the increase in protection afforded by the screened plate as compared to normal armor plate, the values range from 20% to 50% for the face hardened plate and 100 to 280% for the homogeneous plate.

A further feature of interest is that as shown by the caliber .50 firings where several thicknesses of armor plate

of both types were employed with tipping screens, the greatest increase in efficiency of protection resulting from tumbling the bullets, can be attained only if the thickness of armor plate in terms of caliber of projectile is greater than a certain minimum. This minimum for the caliber .50 bullets corresponds to a thickness of either face-hardened, or homogeneous plate of about $1/4$ ". For the face hardened type plate, a net loss in armor efficiency due to the tipping screen was calculated. Thus in the case of screened as well as with unscreened armor plate, the plate cannot be overmatched by the projectile beyond a certain degree for satisfactory performance (see Plot No. 10).

8. Apparent Rough Correlation of Striking Yaw and Penetration

One of the objectives of this report was to determine if any correlation exists between penetration and striking yaw. That the latter could only be roughly ascertained for the caliber .50 firings was discussed on page 4 but from this the writer believes a very approximate correlation, possibly of value, may be achieved. In view of the regularity in penetration obtained, at least with the caliber .50 bullets, with the large variations in measured and hence striking yaws, the inference is that insofar as the influence of striking yaw on the penetration of small arms bullets is concerned, the exact striking yaw is of secondary importance when greater than an approximate value which the writer takes on the basis of these results to be in the neighborhood of 30° - 40° . The true value of yaw at which the ideal curve of limit velocity vs striking yaw would begin to flatten out, or practically that value above which the influence of additional increments of yaw upon penetration would have little effect, would probably be a function of many variables of the plate as type, thickness, hardness, etc, as well as the striking velocity.

9. Reference to Previous Reports on Correlation of Striking Yaw and Penetration of Armor Plate

In Ballistic Laboratory Report No. 42* it was observed for caliber .50 firings against 3" Navy Class B plate, for which only partial penetrations were obtained, that the effect of striking yaw upon normal penetration was rather small. The maximum striking yaws were generally in the vicinity of 12° - 16° , but in a few cases where striking yaws of 30° were attained, the effect was pronounced and disproportionately large compared to that for the smaller yaws. In addition, a $1/4$ " face hardened plate was tested

* B.R.L. Report No. 42. "The Effect of Yaw on Armor Penetration and of Gun Temperature on Yaw". Nov. 11, 1936.

with cal. .30 M1922 A.P. bullets for effect of striking yaw (30° maximum). The results were not conclusive. In these foregoing experiments, large values of striking yaw were secured by either firing in a hot gun, or marred barrel; or nicking the bullets.

In Ballistic Laboratory Report No. 192** there was little observed correlation between penetration and striking yaws for caliber .50 bullets on 1" face hardened armor plate except that the frequency of perforating hits was greatest for small striking yaws. The maximum striking yaws, obtained at 100 yards in the course of the normal acceptance tests for the sources of data, were only about 5°. The irregular character of the results was ascribed mainly to bullet fracture affected probably by yaw with concomitant effects which masked or obliterated any more direct results of striking yaw.

The results in the Fifth Partial Report on Light Armor of the Naval Research Laboratory, already cited, led the authors of that report to the conclusion, "that for caliber .30 bullets an effect of yaw upon penetration of about 1.4% limit velocity increase per degree yaw was found for sample of 17ST Duraluminum, STS armor plate (soft homogeneous), and hard homogeneous armor. The largest yaw effect was measured using a plate of S.T.S. armor hardened to Brinell 370. The smallest yaw effect was obtained on a sample of 1/4" face hardened armor." The maximum striking yaws investigated were in the range below 30°.

** B.R.L. Report No. 192, "The Penetration and Yaw of Cal. .50 M1 A.P. Bullets in 1" Face Hardened Armor Plate," May 29, 1940.

SECTION II

CONSIDERATION OF SOME FEATURES PERTAINING TO SCREENED ARMOR PLATE

1. Armor Plate and Tipping Screen Phases of Problem

The general problem of screened armor plate apparently has two distinct and essential aspects lending themselves to separate investigations, namely: (1) the influence of yaw upon penetration of given armor plate, or the armor plate phase, and (2) the characteristics of tipping screens that will impart the desired yaw properties to the given projectiles, or the tipping screen phase of the problem. This report has been concerned mainly with the factors pertaining to (1) or the armor plate phase. Those relating to (2) are, to reiterate, considered in B.R.L. Report No. 220.

2. Discussion of Armor Plate Phase

Informal conversation with personnel of the Carnegie Illinois Steel Corporation who have been conducting investigations on screened armor plate have tended to corroborate the author's tentative remarks on the effect of yaw upon penetrations. A further point of interest brought out was the satisfactory performance of widely varying (in physical properties) homogeneous steel plate as the armor plate component. However, as mentioned on page 9 the first phase, (1) or the effect of yaw upon penetration, requires a thorough systematic program to evaluate adequately the pertinent striking yaw--penetration characteristics of homogeneous plate. Having determined an optimum or satisfactory striking yaw value for any given plate and projectile, the proper tipping screen to be employed can be ascertained from a detailed knowledge of the yaw vs distance beyond tipping screen behaviour of various screens with placement.

3. Data for Tipping Screen Phase

Graphs of this behaviour are given for 24 ST Duraluminum and some samples of homogeneous steel plate in B.R.L. Report No. 220. Further results for varying samples of steel plate including mild steel and stainless 18-8 were obtained by the Proof Department, and are presented in appendix B.

4. Presentation of Tipping Screen Characteristics

In view of the method of analysis or presentation employed in representing the tipping characteristics of any given material in this section as well as the obliquity performance of armor plate in a subsequent section, possibly

a brief discussion is warranted.

As the maximum yaw of the yaw-distance beyond tipping screen cycle is in general a function of the two variables, thickness and angle of obliquity for any given quality tipping screen material, a complete representation of the tipping screen performance as represented by maximum yaw would be obtained by a three dimensional plot of maximum yaw of yaw-distance cycle as a function of thickness and angle of obliquity. The graphs in Appendix A. No's: 22 and 23 from B.R.L. Report No. 220 are sections of such a plot. For purposes, however, of determining the most efficient disposition of the plate at obliquities and comparing the tipping screen efficiency of different materials, a change in one of the parameters is convenient, namely the substitution of equivalent projected thickness in place of the angle of obliquity. The equivalent projected thickness is defined in accordance with the terminology used previously as the thickness of tipping screen material corresponding to the projected weight of the inclined tipping screen on unit area normal to the bullet trajectory.

Numerically, if:

t_a = actual thickness of tipping screen.

t_p = equivalent projected thickness, of tipping screen.

θ = angle of obliquity of tipping screen.

$$t_p = \frac{t_a}{\cos \theta}$$

Where the tipping screen material is other than steel, t_p is expressed in terms of an equivalent weight of steel plate, and is designated as "equivalent projected thickness in terms of steel".

The plot of maximum yaw of yaw distance cycle vs actual and projected thickness is then a surface characterizing the tipping screen performance of any material with respect to certain desirable aspects. Inasmuch as the length of cycle of the yaw vs distance behind tipping screen curve decreases with increasing maximum yaw of the cycle as produced by any tipping screen (for a given projectile and firing conditions) as indicated in Plot-No. 24, Appendix A, the steepness of slope of the yaw distance curve is also indirectly included in the above representation.

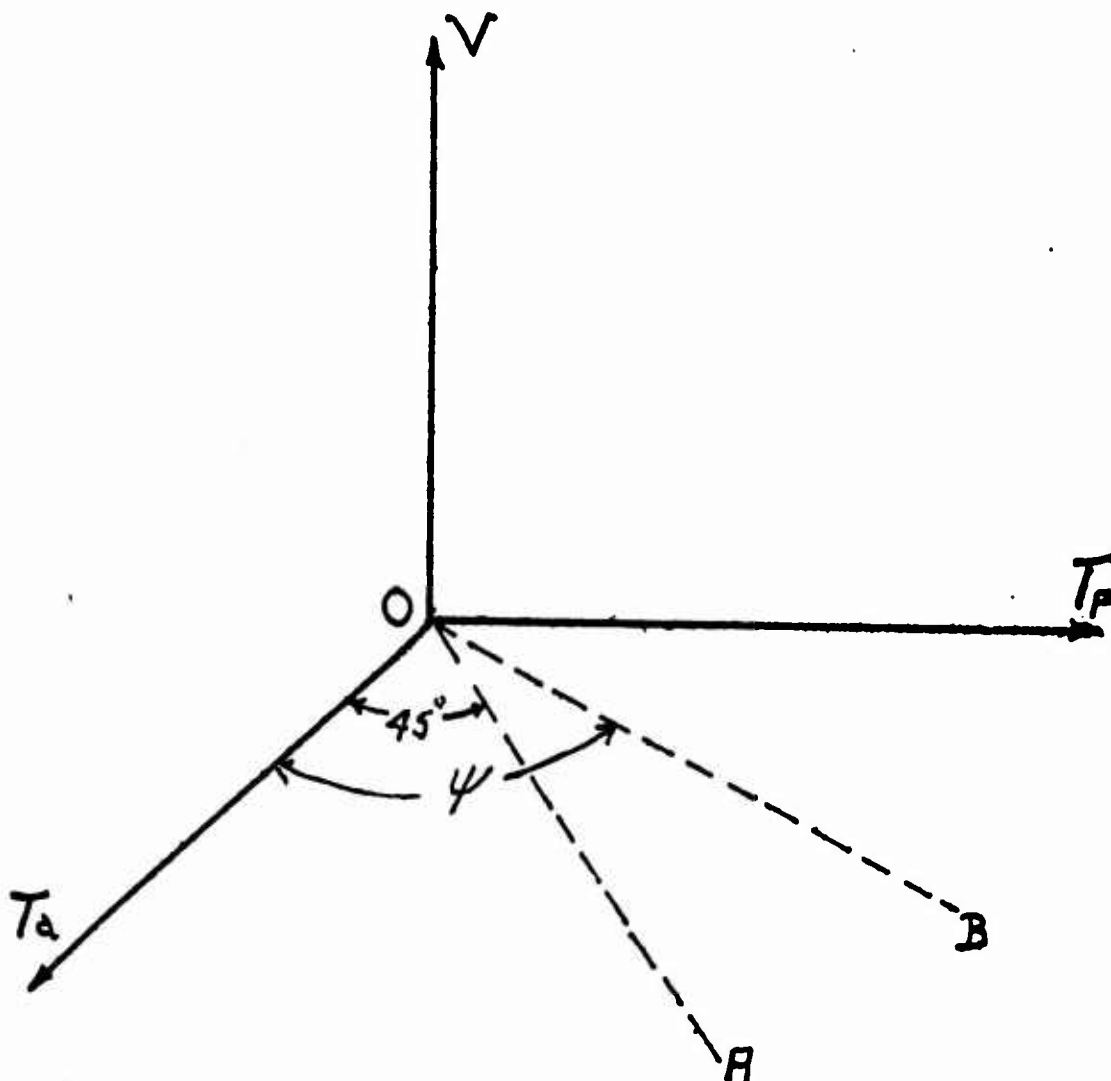


Fig. 3

It will be seen that the entire surface of maximum yaw Fig. 3 is contained in the segment of the quadrant bounded by the two vertical planes, VOT_P and VOA at 45° to each other. All points lying in the plane VOA correspond to plates at normal impact, points lying in any other vertical plane through VO such as VOB having the same angle of obliquity determined by the slope of the intersection OB according to the relation:

$$\cos\theta = \cot\psi.$$

The information in such a plot is advantageously represented in a two coordinate system by projecting the intersections of the limit velocity surface with vertical planes through VO , or parallel to VOT_P corresponding to different actual thicknesses of tipping screens at varying obliquity on plane VOT_P . The data on tipping screens contained in appendices A and B have been plotted in the latter manner. In addition the average curves obtained at Watertown Arsenal on the Carnegie Illinois Corporation's "sandwich" tipping screens consisting of two plates separated by a $1/2$ " layer of rubber "air foam"

were analyzed for the same end. The results are given in Plots No. 11 and 12. The component parts of the "sandwich" tipping screens are given in detail in Table VI-B with the same corresponding plate designations as employed in Plots No. 11 and 12.

The superiority of duraluminum as a tipping screen material to the others tested can thereby be inferred for both calibers of small arms bullets although information for dural in thicknesses greater than 1/8" for caliber .50 firings is lacking. In addition to the general representation of the tipping screen efficiency of any given material as in Plots No's. 11 and 12, a further analysis seems to be required so as to enable the proper choice of tipping screen for a particular application. This is discussed in the following section.

5. Comparative Merits of Tipping Screen Materials Producing Given Value of Yaw

Assuming that a given value of striking yaw, estimated to be about 35°, would have to be obtained for satisfactory performance of the armor plate member, a comparative listing was made of tipping screens and their disposition required to produce this given value of yaw. For this purpose the detailed yaw vs distance beyond screen curves of B.R.L. Report No. 220 and Appendix B were utilized. In addition data from the average curves obtained at Watertown Arsenal on the Carnegie Illinois Corporation's "sandwich" tipping screen plates were included. Only the results for caliber .50 bullets have been included in view of the greater amount of experimental data available. They are given in Tables VI and graphically portrayed in Plot No. 11. In general such an analysis would be required only for the most efficient tipping screen materials. However, all the data available have been included in this instance to further illustrate some of the comparative characteristics of tipping screens.

Fundamentally, the detailed "yaw vs distance curves" are the basis of this and similar analysis. The dispersion in such curves is of significant importance in indicating the uniformity in tipping action of the screen. Where wide dispersion or erratic results are truly found, the actual performance at the tipping screen in combination with armor plate may have to be ascertained in detail.

The resulting curves of yaw vs distance beyond tipping screen for a number of rounds may be bounded by two envelopes, the upper one indicating the maximum yaw obtained at any given distance, and the lower envelope, the minimum yaw at

any given distance. For the analysis in Table VI-A, the required distance to attain the given yaw was determined from the maximum and minimum envelopes as well as the average of all curves for any tipping screen. The recommended distance for the armor plate from the tipping screen would be that evaluated from the minimum envelope. However, in Plot No. 13 the armor plate-tipping screen distances shown are those determined from the average of the yaw-distance curves inasmuch as the detailed results were not available from the Watertown Arsenal letter.

Such representations as in Plot No. 11 may be of value in indicating directly the appropriate tipping screens to be employed for any defined application. From this plot of a limited amount of data it would appear that tipping screens of duraluminum are appreciably more efficient than steel. Heavier dural screens up to at least 1/4" in thickness should be investigated to obtain appreciable yaw effects at distances of about 1' such as obtained with the steel screens.

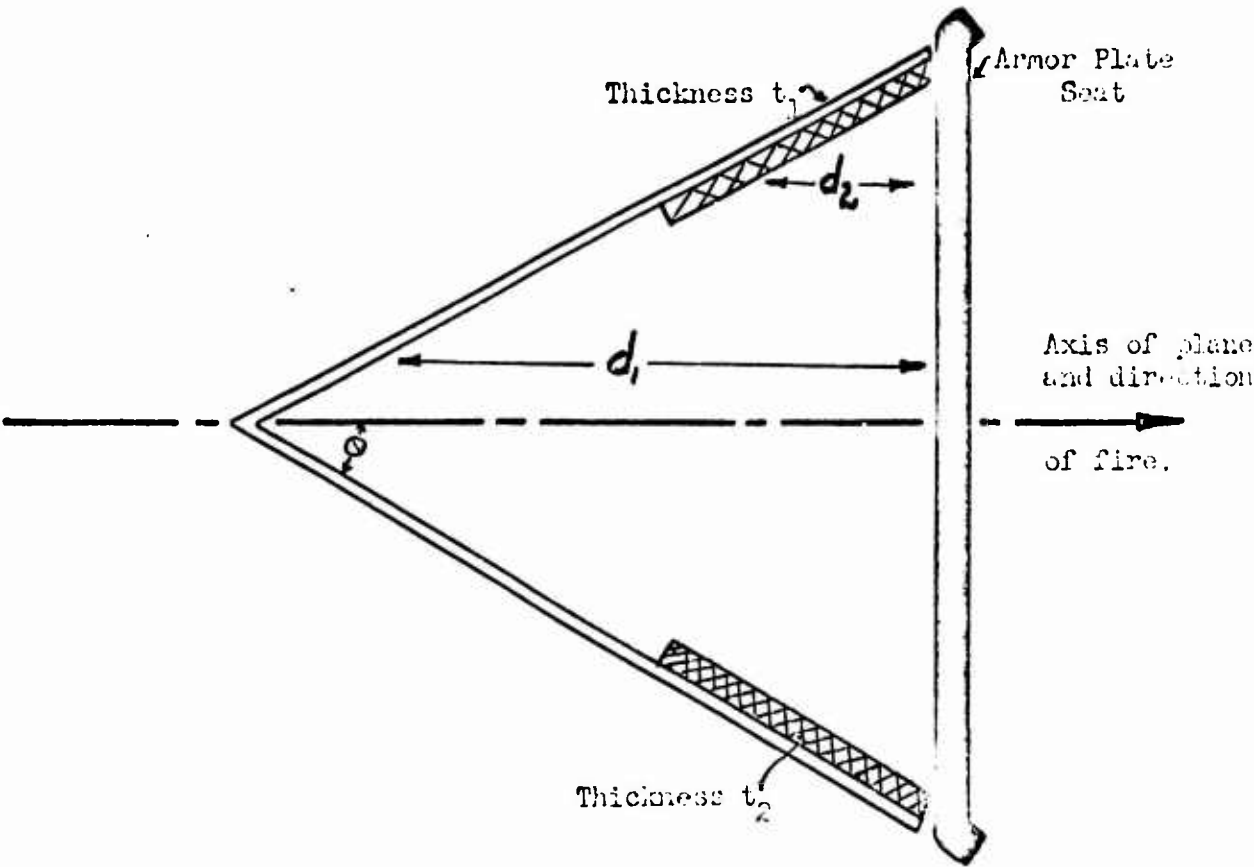
6. General Method of Approach to Solution of Given Problem

With adequate information as to the characteristic yaw surface discussed on page 12 and the subsequent more detailed analysis of the most satisfactory specific combinations as in Plot No. 13, the choice of a suitable tipping screen for any given application may be inferred. Thus for the problem of the protection of the pilot in aircraft one of the proposed designs following clearly from screened armor plate experimentation has the pilot's seat of armor plate or dural and tipping screens disposed in back in the form of a V as indicated in Fig. 2. However, in view of the varying distance between screen and plate the desired tumbling of the bullets may not properly obtain for all included shots. Thus if d_1 be the proper distance for adequate tumbling of a bullet with trajectory along the axis, d_2 may not. A second plate of thickness of t_2 could however, be chosen from the foregoing type of analysis on page 14 to make the combination screen produce the desired tipping action within the specified distance limits.*

Of course in this as with other problems involving the use of tipping screens, numerous factors may inherently mitigate against a precise quantitative analysis. Thus the

*The rough approximation that individual tipping screens may be combined with a resulting effect not greatly different from that of a single plate of equivalent thickness is taken from the results for the "sandwich" or composite screens of Plot No. 13.

Figure 2



(15A)

influence of large incident yaws upon the tipping action of a given screen remains to be determined. In B.R.L. Report No. 220, it was shown that the tipping action of the screen was little influenced by the incident yaw when the latter remained below 10° . However, in the given problem, the bullet in passing through bulkheads may have a large incident yaw $>20^\circ$ by the time it reaches the tipping screen. Such factors can be best evaluated in direct empirical tests of installations. Basically, though, the first approximate indication as to the proper installation should be correctly given by analysis based on the fundamental yaw characteristics of tipping screen materials.

SECTION III

PERFORMANCE OF COMPARATIVE HOMOGENEOUS ARMOR PLATE AT OBLIQUITIES

In Table V and on page 7 an estimate was made of the increase in armor efficiency attributable to the use of tipping screens, the basis of comparison being the unshielded armor plate at normal impact. As the ballistic efficiency of homogeneous armor plate increases greatly at the higher obliquities, a very informative evaluation would be afforded by ascertaining the advantages to be gained by either shielding a given "quality" homogeneous plate or disposing it at the optimum value of thickness and obliquity for the desired protection.

1. Analysis of Recent Obliquity Results for Carnegie Illinois Homogeneous Plate

Fortunately for the foregoing purpose the results of a detailed series of obliquity firings on Carnegie Illinois homogeneous plate similar in "quality" to that employed in the screened armor plate tests were available in recent Firing Records, references being given in the appropriate plots of the data. The previously given information for the case of normal impact was obtained from these Records. The obliquity data from the sources mentioned have been plotted according to the manner discussed on page 12 in Plots No. 14-21. Although the homogeneous plate employed in the tipping screen experiments belonged to the medium Brinell hardness series, the obliquity data for the low and high hardness series of plates are also included partly for the sake of completeness.

2. Comparison of Screened Homogeneous Plate and Homogeneous Plate at Obliquity

Corresponding to the type of comparison made in Tables V, a similar comparison was made for the homogeneous plate at obliquities and the screened homogeneous plate through the aid of the above plots. Wherever possible, the optimum thickness and obliquity of plate that would possess the requisite limit velocity was chosen as the basis of comparison for the unshielded homogeneous plate. Unfortunately the clear indication from Plots No. 14 - 16 and 20 is that for the caliber .30 bullets the optimum efficiency would have been obtained for all three series of plates at thickness less than the lowest value tested; namely, 1/4". The data for the caliber .50 firings, Plots No. 18, 19, however, were satisfactory for the purpose. The results of the comparison taking the best values obtainable for the caliber .30 tests and the optimum values for the caliber .50 are presented in Tables VII which are similar in their listing to Table V.

For Table VII-A the obliquity data for the medium Brinell hardness series of plates (average B.H.N. 338) similar in quality to that of the screened armor plate tests was employed, (Plots No. 15 and No. 18) and therefore the comparison in performance is strictly valid for a specific type of medium hard homogeneous armor plate. By replotting the data in Plots No. 14 - 22 the fact can readily be ascertained that for the given bullets, the obliquity performance of the armor plate increased with Brinell hardness in the range of hardnesses tested. To secure a comparison between the screened armor plate and the best of the homogeneous plates at obliquities, the data for the series of high hardness plates (average B.H.N. 435) in Plots No. 16 and 19 were utilized to obtain Table VII-B. The results of both tables for the caliber .50 firings indicate that the screened armor plate possesses a significantly greater protective efficiency than the unscreened plate at obliquities for thicknesses equivalent in about .58" of steel. For lesser thicknesses, equivalent in weight to about .34" of steel and corresponding to a lower degree of protection, both methods of securing high ballistic efficiency appear equally satisfactory. For the caliber .30 projectiles, there was no appreciable difference in the respective efficiency merits considering the hardest homogeneous plate for obliquity performance. As mentioned previously, however, the data for the caliber .30 projectiles are inadequate and the writer believes that were the optimum values available for the homogeneous plates at obliquities, there would be little difference in protective efficiency of both schemes.

The above results and conclusions to be deduced therefrom are valid for a given type of homogeneous armor plate the characterization of the material being as complete as available information permitted. Further generalizations appear to be unwarranted in view of the lack of sufficiently comprehensive data of similar nature to that at hand for this report. The great increase in ballistic performance, particularly of homogeneous plate, resulting when the small arms projectile is made to strike the plate broadside either through large incident yaw or oblique fire, has as one of its basic causes bullet fracture and its associated effects. Hence the results discussed in the report are a function of the test instruments employed, namely the specified small arms ammunition as well as the armor plate and tipping screens themselves. Any change in ammunition either in physical shape, material, or heat treatment that could influence particularly the behavior under various conditions of impact might be expected to change the results of this report.

3. Consideration of other Features of both Methods of Securing High Armor Plate Efficiency

There are certain aspects of both systems of armor

protection i.e--screened armor plate and disposing armor plate at obliquity that have been ignored thus far, but which must be obviously considered as concomitant features of practical importance in addition to the magnitude of the limit velocities. Many of these are of a detailed nature depending upon the specific application. Some of the more important ones, however, that may be classified as general are:

- (a) The reliability of the protection to shots that may deviate from the normal behaviour expected, viz., the yawing behaviour of bullets.
- (b) The effect of splash and spalls from the varying components of the armor plate installation.
- (c) The facility of obtaining the armor plate installations satisfying the required standards. This is closely allied with the tolerances permissible in the specific type, analysis, and metallurgical treatment of the requisite plate.

The writer is unable to discuss properly point (a) with respect to the two schemes of armor installation considered in this report. For all future tests of these or other protective arrangements, the recommendation is made that a group of shots be fired at the limit velocity, particularly where the machine gun may be so employed as to ascertain (a) from sufficient trials.

Concerning (b), the indication is that greater splash results from the use of tipping screens, and for particular applications this might be objectional.

From the present amount of data available to the writer, no categorical assertion concerning (c) is justified. However, according to comments of a representative from the Carnegie Illinois Steel Corp. referred to on page 11 it appears likely that there would be far greater variations permissible in the physical and metallurgical properties of homogeneous armor plate as a component of screened armor plate than for homogeneous plate employed at obliquities.

Recommendations

In view of the excellent results shown by the screened armor plate combinations of the First Development Test of Screened Armor Plate at A.P.G., Particularly those combinations wherein homogeneous armor plate was employed as a component, further programs of investigation are

warranted. These would involve two phases, namely:

(1) the influence of large striking yaw ($\geq 20^\circ$) upon penetration of homogeneous plate including mild steel, and

(2) the characteristics of tipping screens that will produce the desired yaw behaviour in given projectile for specific applications. If need should arise for the production of large yaw within small distances it appears that investigations of 1/4" duraluminum tipping screens would be desirable.

Acknowledgement

The author wishes to express his appreciation of the criticisms and suggestions offered by Mr. Tolch and Mr. Kent in the preparation of this report.

J. Leder

TABLE I

LEGEND

Abbreviation

P.	Partial (penetration)
C.	Complete (penetration)
Dia. Pen.	Diameter penetration
Pun. S.	Punching started
S. B.	Slight bulge
M. B.	Medium bulge
L. B.	Large bulge
C. I. P.	Core in plate

TABLE I

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw	2nd Yaw Card Yaw	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Diebold, 5/8" No. 6-138-700-36, Face Hardened</u>							
<u>1/8" Dural. 5.5 ft. in front of plate at angle of 60°</u>							
<u>Angle of Plate, Normal, Yaw Cards 20" and 46" in front of plate</u>							
1	.50 M1	41° approx.	50° approx.	87° Jacket probably stripped at nose	2709	P	
2	"	31° approx.	45° approx.	61.9° Jacket at nose stripped slightly	2777	P	S.B. Pen. d=1/8"
3	"	30° approx.	62° approx.	320° Jacket at nose stripped slightly	2876	P	Pun. S. Pen. d=1/4" Cracks on previous impact.
4	"				2975		Hit plate frame.
5	"	16° approx.	33° approx.	61° Jacket slightly stripped at nose	3059	C	Pun. S. crack 1-1/4" on back Pen. d=1/4"
6	"	-	33° approx.	98° Jacket slightly stripped at nose	3074	C	Pun. S. with circula: crack around punching
7	"	-	33° approx.	2.8° Jacket slightly stripped at nose.	2999	P	S.B. Pun. S. Crack 1-1/2" Pen. d=1/4"

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>American Car and Foundry 1/4" No. G 111 G.E., Face Hardened</u>							
<u>1/8" Dural. 5.5 ft. in front of plate at angle of 60°</u>							
<u>Angle of Plate Normal, Yaw cards 20" and 46" in front of plate</u>							
8	.30 M1922	-	-	Jacket stripped, core broken by screen	2291	P	Plate pockmarked from fragments
9	"	30°-50° estimated	41°	171° Jacket still on side of core on card 1. Completely stripped card 2.	2531	P	Pun. S. 1/4" crack on back
10	"	50°-70° estimated	75°	93.5° Jacket stripped and still on end of core on card 1. Completely stripped card 2.	2641	C	Dia. pen. 7/16" x 9/16"
11	"	-	-	89.4° of tip On 1st card tin of core broken, remainder core still in jacket. On 2nd card base has separated from jacket.	2582	P	One piece of core started punching.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>American Car and Foundry 1/4" No. Gill G.E., Face Hardened</u>							
<u>1/8" Dural 5.5 ft. in front of plate at angle of 60°</u>							
<u>Angle of Plate Normal, Yaw cards of 20° and 46° in front of plate</u>							
12	.30 M1922	0°	6°	10°	Jacket stripped Indication is that core is whole although this is dubious.	2599	P Face at plate pock marked
13	"	78°	80.9°	187.8°	Jacket stripped still on side core 1st card. Jacket completely stripped 2nd card	2633	P Face of plate pock marked
14	"	60.5°	35.4°	78.1°	59.3°	2664	C Dia. pen. 7/16" x 1-1/2" Projectile passed through plate.
15	.30 M2	52.0°	74°	76.8°	200.4°	2642	C Dia. pen. 9/16" x 9/16" Bullet Yawed 15° when passing thru plate.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
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American Car and Foundry 1/4" No. G-111 G.F., Face Hardened

1/8" Dural 5.5 ft. in front of plate at angle of 60°

Angle of Plate Normal. Yaw cards at 20° and 45° in front of plate

16	.30 M2	52.9	354.4	76.8	60.5	Jacket completely stripped	2586	P	Plate pock marked.
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1/8" Dural 4 ft. in front of plate at 60° Angle

Angle of Plate Normal. Yaw Card 20" Front of Plate

17	.30 M1922	4 4°	230°	No second		Indication is core is completely stripped	2575	P	L.B. Pun. S. Hit in previous impact
18	"	61.6°	359°	No second		Jacket stripped completely	2708	C	Pin hole light Large punching almost out.
19	"	-	-	No second		Jacket stripped completely. Core broke in two.	2658	P	
20	.30 M2	50° 75° est	91.3°	No second		Core partially out of jacket	2651	C	Dia. pen. 1" x 1-1/2" Hit previous impact.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw	2nd Yaw Card Yaw	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>1/8" Dural 4 ft. in front of plate at 60° Angle</u>							
<u>Angle of Plate Normal, Yaw Card 20" Front of Plate</u>							
21	.30 M2	76.8°	64.1°	No second	Jacket stripped completely	2692	P Pun. S.
22	.30 M2	81.1	136.5°	No second	Jacket stripped completely	2700	C Dia. pen. 5/8" x 5/8"
23	.30 M2	13.4	7°	No second	Jacket stripped, Part of core may be broken and still in jacket.	2703	C Dia. Pen. 9/16" x 9/16"
24	.30 M2	78.9°	348.5°	No second	Jacket stripped completely	2717	C Dia. pen. 5/16" x 1"

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>American Car and Foundry Plate 1/4" No. G35GE, Face Hardened</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal. Yaw cards 21" and 46" in front of plate</u>							
10	.50 ML	Splash	39° approx.	33.4° Jacket partially stripped at nose	1773	C	Dia. Pen. 1-1/4" x 1-1/2" B.S. 2-1/2" x 3" incomplete. Hit screen frame holder.
11	.50 ML	Missing			1458	C	C.I.P. Hit wood of yaw card frame
12	.50 ML	19° approx.	38° approx.	178.0° Part of jacket stripped at nose.	1401	P	S.B.
13	.50ML			No record	Lost		Hit frame.
14	.50ML	5° approx.	14° approx.	214° Jacket stripped very little	1430	P	S.B.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen On Bullet	Strik. Vel.	Pen.	Result
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Carnegie 1" Homogeneous No. 1545891/8" Dural. 5.5 ft. in Front of plate at 60° AngleAngle of Plate, Normal. Yaw Cards21" and 46" Front of Plate

1	.50M1			No record	Lost	P	Hit yaw frame
2	.50M1			No record	2967	P	Hit yaw frame
3	.50M1	22° approx.	41° approx.	65° Jacket partially stripped at tip	3063	P	S.B.
4	.50M1	Interpretation difficult splash	15.8°	100.5° Indication is bullet is practically whole with little stripping of jacket.	3103	P	C.I.P. M.B.
5	.50M1	Interpretation difficult, splash	23° approx.	38.6° Jacket partially stripped at nose.	3173	P	S.B.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Orient.	2nd Yaw Card Yaw Orient	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1" Homogeneous No. 154539</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal. Yaw Cards</u>							
<u>21" and 46" Front of Plate</u>							
6	.50M2	Interpretation difficult, splash	25° approx.	Jacket partially stripped at nose	3200	P	S.B.
<u>Carnegie 1/2" Homogeneous Plate No. 39</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal. Yaw Cards at 21" and 46" Front of Plate</u>							
1	.50M1	47° approx.	90°	Interpretation difficult, splash	Jacket stripped at nose	2693	P L.B.
2	.50M1	27° approx.	2°	47° approx.	37.6°	Jacket stripped very slightly at nose	2790 C C.I.P., L.B. Pun. S., 1" Crack of light.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/2" Homogeneous Plate No. 39</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Cards at 21" and 46" Front of Plate</u>							
3	.50M1	Interpretation difficult, splash.	44.3°	80.4°	Jacket stripped slightly at nose	2747	P L.B. Pun. S.
4	.50M2	35° approx.	47.1°	53° approx.	103°	Jacket stripped slightly at nose	2757
5	.50M2	20° approx.	6.8°	37° approx.	50°	Jacket slightly stripped from nose	2796
6	.50M2	34° approx.	22.4°	54° approx.	269.5°	Jacket partially stripped from nose	2870
7	.50M2	15°-25° estimated	23°	39.5°	75°	Jacket partially stripped at nose	2974
7 (Duplicate No.)	.50M2	32° approx.	4.8°	62° approx.	59.5°	Jacket partially stripped at nose	3013
							P L.B. cracking started

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/2" Homogeneous Plate No. 39</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Card at 21" and 46" Front of Plate</u>							
8	.50M2					3057	Hit dural frame
9	.50M2	20°-40° estimated	15°-25° estimated	187.2° Large amount of splashing. Jacket possibly partially stripped	3031		Hit Previous impact
10	.50M2	22° approx.	35° approx.	47° Jacket partially stripped at nose.	2737	P	L.B.
11	.50M2	27° approx.	30°-50° estimated	72° Most of Jacket still on core	2621		Hit in previous impact
12	.50M2				3116		Hit yaw card frame
13	.50M2	15° approx.	14.3°	- Interpretation difficult because of splash. Most of jacket on core.	3183	C	Dia. Pen. 15/16" x 1"

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
 FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/2" Homogeneous Plate No. 39</u>							
<u>1/8" Dural. 5.5 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Cards at 21" and 46" Front of Plate</u>							
14	.50M2	12° approx.	74.8° approx.	22° approx.	115.1° Interpretation difficult 3123 because of splash.	C	Dia. Pen. 3/4" x 1-9/16". Parts of bullet on both sides of plate
15	.50M2	24° approx.	31° approx.	48° approx.	76.1° Jacket stripped off at tip only	C	Dia. Pen. 1", Crack of light.
16	.50M2	-	-	22° approx.	22.1° Records splashed. Indication is jacket is still on.	C	Dia. Pen. 5/8" x 1-3/8". Parts of bullet both sides of plate.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw	2nd Yaw Card Yaw	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/4" Homogeneous Plate No. 28</u>							
<u>1/8" Dural. 4 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Cards at 22" Front of Plate</u>							
1	.30 M1922	10° Esti- mated	233° Dubious	No second	Indication is that jacket is completely stripped, core intact	2552	C Dia. Pen. 3/8" x 3/8" Distance from dural. to impact 4' 5"
2	.30 M1922	-	-	"	Jacket completely stripped; core broke in two.	2434	C Dia. Pen. 1/4" x 3/8" Bullet hit plate on nose.
3	.30 M1922	77.9°	68°	"	Jacket stripped completely	2429	P S.B.
4	.30 M1922	-	-	"	Indication is that core may be broken.	2593	P S.B.
5	.30 M1922				No record	2664	P S.B.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIR'D THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw	2nd Yaw Card Yaw	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/4" Homogeneous Plate No. 28</u>							
<u>1/8" Dural. 4 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Caris at 22" Front of Plate</u>							
6	.30M1922	43.2°	55°	No second	Jacket stripped completely	2934	P L.B., Pun. S.
7	.30M1922	61.9°	349°	"	Jack t stripped completely	3094	P Pun. S., C.I.P.
8	.30M1922	52.9°	12°	"	Jacket stripped completely	3179	C Pun. S. Pinhole
9	.30M2	81.1°	38.1°	"	Jacket stripped completely	3155	C C.I.P. Pun. S. Pinhold light
10	.30M2			"	Missing	3089	Hit previous impact
11	.30M2	Estl- mated 60°-80°	74.3°	"	Jacket partially stripped at nose	3134	C C.I.P. Pun. S. Pinhole light.

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OF DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw Orient.	2nd Yaw Card Yaw Orient.	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
<u>Carnegie 1/4" Homogeneous Plate No. 28</u>							
<u>1/8" Dural. 4 ft. in Front of Plate at 60° Angle</u>							
<u>Angle of Plate, Normal, Yaw Cards at 22" Front of Plate</u>							
12	.30M2	43.2°	79°	No second	Jacket stripped completely	3068	P L. B. Pun. S.
13	.50M1	47° approx.	26.1°	47° approx.	Jacket partially stripped clear at nose	2230	C Dia. Pen. 1/2" x 3/16" fragments of bullets P.T.P.
14	.50M1	Estimate 40°-60°	34.2°	Estimate 40°-60°	Jacket partially stripped at nose	2062	P M.B.
15	.50M1	-	Estimate 40°	Estimate 89°	Jacket partially stripped at nose	1863	C Dia. Pen. 7/16" x 1-13/16"
16	.50M1					1655	Hit yaw card frame.
17	.50M1	Estimate 20°	131.5°	Estimate 24°	Poor records on yaw cards. Jacket stripped partially at nose..	1570	P S.B. Cracking started

TABLE I (CONT'D)

YAW AND PENETRATION OF SMALL ARMS BULLETS
FIRED THROUGH TIPPING SCREEN OR DURALUMINUM

Rd. No.	Bullet	1st Yaw Card Yaw	2nd Yaw Card Yaw	Card Orient	Effect of Screen on Bullet	Strik. Vel.	Pen.	Result
18	.50M1	22.8°	35.3°	137°	Jacket probably damaged at nose slightly	1576	C	Dia. Pen. 5/16" x 1-3/4"
19	.50M1	46° approx.	47° approx.	312°	Jacket stripped at nose slightly	1632		Hit in previous impact
20	.50 M1	35.6°	69.8°	83.6°	Bullet intact	1633	C	Crack of light 1-7/16" long. Pun. S. L.B.

TABLE II

Ballistic Limits and Yaw Values from Results of Table I

Bullet	Average Yaw in Deg. 1st Card	2nd Card	Range in Yaw, Deg. 1st Card	2nd Card	Low C	High P	B Limit	Remarks
A.C.F. 1/4" F.H. No. G111 GE								
D = 5.5 ft., d ₁ = 46", d ₂ = 20"*								
30M1922	48° (5)+	46° (5)	0 - 78°	6° - 78°	2641	2633	2637	Bullet with yaw 0° 1st, and 6°, 2nd card gave light P on 2599 f/s. Bullet with yaw 78°, 2nd card gave complete on 2664 with Pr. P.T.P.
.30M2	53° (2)	77° (2)	52° - 53°	76.8-76.8°	2642	2586	2614	
D = 4 ft., d ₂ = 20"								
.30M1922	None	33° (2)		4° - 62°	2708	2658	2682	
.30M2	None	62° (5)		13° - 79°	2700	2692	2696	
A.C.F. 1/4" F.H. No. G85 GE								
D = 5.5 ft., d ₁ = 46", d ₂ = 21"*								
.50M1	13° (2)+	30° (3)	5° - 19°	14° - 38°	1458	1430	1444	The few complete measurements indicated yaws were on ascending branch or near maximum at 2nd yaw card; striking yaws estimated to be greater than 20° - 30° at least.

* Notation for distances as in Fig. 1.

+ Numbers in parenthesis indicate number of values included in average.

TABLE II (CONT'D)
Ballistic Limits and Yaw Values from Results of Table I

Bullet	Average Yaw in Deg. 1st Card	2nd Card	Range in Yaw, Deg. 1st Card	2nd Card	Low C	High P	Limit
Diebold 5/8" F.H. No.:6-138-700-36							
D = 5.5 ft., d ₁ = 46", d ₂ = 20"							
.50ML	29° (4)	43° (6)	16°-41°	33°-62°	3059	2999	3029
All measurements indicate yaws were on ascending branch or near maximum at 2nd yaw card; striking yaws estimated to be greater than 30° at least.							
Carnegie Illinois 1/4" Homogeneous No. 28							
D = 4 d ₂ = 22"							
.30ML22	None	49° (5)+	None	10°-78°	2434	2429	2432
On 2 completes at 2552 and 2434 f/s The yaw on 2nd card was 10° for one and probably small for other from indication of impact. Partialals obtained for velocities up to 3084 f/s with large yaws.							
.30M2	None	65° (3)	None	43°-81°	3134	3068	3101
.50ML	37° (6)	46° (7)	20°-47°	24°-70°	1576	1570	1573 ++
All striking yaws except one estimated to be at least greater than 20°.							

* Notation for distances as in Fig. 1
+ Numbers in parenthesis indicate number of values included in average.
++Changed from value given in firing record.

TABLE II (CONT'D)

Ballistic Limits and Yaw Values from Results of Table I								
Bullet	Average Yaw in Deg. 1st Card	2nd Card	Range in Yaw, Deg. 1st Card	2nd Card	Low C	High P	B Limit	Remarks
<u>Carnegie Illinois 1/2" Homogeneous Plate No. 39</u>								
<u>D = 5.5 ft., d₁ = 46", d₂ = 21"*</u>								
.50M1	37° (2)	46° (2)	27°-42°	44°-47°	2790	2747	2769	All except few dubious values of yaw on ascending branch; striking yaw at least 20°-30°.
.50M2	25° (11)	39° (11)	12°-38°	15°-62°	3123	3013	3068	Except for few doubtful ones.
<u>Carnegie Illinois 1" Homogeneous Plate No. 154589</u>								
<u>D = 5.5 ft., d₁ = 46", d₂ = 21"</u>								
.50M1	22° (1)	27° (3)		16°-41°			3173	Slight bulge on 3173 f/s with yaw of 23° on 2nd card.
.50M2	-	25° (1)					3200	Slight bulge, 3200 f/s with yaw as given.

* Notation for distances as in Fig. 1.
 + Numbers in parenthesis indicate number of values included in average.

TABLE III-a

Penetrations of Face Hardened Armor PlateTipping Screen of 1/8" Duraluminum at 60° unless Otherwise Indicated

Plate Thick Inches	Armor Plate Normal to Direction of Fire		Bullet		Limit Velocity	Equiv. F
	Tipping Screen	Total Equiv. Projected Thick. Inches	Cal.	Model		
(1) 1/4"	None	.250	.30	M1922	2217	80,500
	Angle 45° at 5.5 ft.	.313	"	"	2419	79,000
	At 5.5 ft.	.339	"	"	(2631 approx.)	82,300
	at. 5.5 ft.	.339	"	M2	2548	81,000
(2) 1/4"	None	.250	.30	M1922	2072	75,500
	None	.250	.30	M2	2112	78,000
	At 4 ft.	.339	.30	M1922	2682	84,000
	At 4 ft.	.339	.30	M2	2696	85,500
	At 5.5 ft.	.339	.30	M1922	2637	82,600
	At 5.5 ft.	.339	.30	M2	2614	82,700
(3) 1/4"	None	.250	.50	M1	1282	60,300
	At 5.5 ft.	.339	.50	M1	(1486 approx.)	60,000
(4) 1/4"	None	.250	.30	M2	2003 Dubious	74,000 Dubious
	None	.250	.50	M1	1220	57,200
(5) 5/8"	At 5.5 ft.	.339	.50	M1	1444	53,200
	None	.625	.50	M1	2195	65,200
	At 5.5 ft.	.714	.50	M1	3029	84,200

* Distance of armor plate behind screen indicated.

(1) Diebold Plate No. 189-X236-535, F.555 B. 444

(2) A.C.F. Plate No. G-111 G.E.

(3) Diebold Plate No. 188-X237-537, F. 514 B 444, 429

(4) A.C.F. Plate No. G85 G.E.

(5) Diebold Plate No. 6-138-700-36

TABLE III-b

Penetrations of Homogeneous Armor PlateTipping Screen of 1/8" Duraluminum at angle of 60° Unless Otherwise Indicated

Armor Plate Normal to Direction of Fire						
+Plate Thick. Inches	*Tipping Screen	Total Equiv. Projected Thick. Inches	Bullet Cal.	Model	Limit Velocity	Equiv. F.
(1) 1/4"	None	.250	.30	M2	1191	44,000
	At 4'	.339	"	M2	3101	98,400
	At 4'	.339	.30	M1922	2432	76,000
	At 5'6"	.339	.50	M1	1573	63,500
(2) 1/2"	None	.500	.50	M2	1344	44,600
	At 5'6"	.589	.50	M2	3068	94,000
	At 5'6"	.589	.50	M1	2769	84,900
(3) 1"	None	1.00	.50	M1	2398	56,250
	At 5.6"	1.09	.50	M1	3173(P)	>71,300
			.50	M2	3200 (P)	>72,000

* Distance of armor plate behind screen indicated.+ All homogeneous plate of Carnegie Illinois Manufacture

- (1) Plate No. 28, or No. 134459, Heat No. 21430, B.H.N. 333
Ballistic limit for unscreened plate obtained from A.P.G. Firing Record 20703, A301 for similar plate No. 134459-3
- (2) Plate No. 39 or No. 154590-G, Heat No. 15353, B.H.N. 324
Ballistic limit for unscreened plate obtained from A.P.G. Firing Record 20703, A301 for similar plate No. 154590-H.
- (3) Plate No. 154589, Heat No. 15353, B.H.N. 341
Ballistic limit for unscreened plate obtained from A.P.G. Partial Reports of Armor Plate, No. 320.

TABLE IV-A

Average of Penetrations for Face Hardened Armor Plate from Table IIITipping Screen of 1/3" Duralumin at 60° Unless Otherwise IndicatedPlate Normal to Direction of Fire

Plate Tipping Thick Screen	Total Equiv. Projected Thick., In.	Cal. Bullet	Average Limit Velocity f/s	*P.E. (f/s)	Average F	*P.E.	No. of Determin.
-------------------------------	--	----------------	-------------------------------------	----------------	--------------	-------	---------------------

1/4" None (Angle 45°)	.250	.30	2134	58	73,000	1730	3
At 5.5 ft.	.313	"	2419	-	79,000	-	1
At 4 ft.	.339	"	2639	9	84,700	900	2
At 5.5 ft.	.339	"	2608	29	82,100	560	4

None	.250	.50M1	1251	37	59,700	1360	2
At 5.5 ft.	.339	"	1465	25	59,100	1080	2
5/8" None	.625	.50M1	2195	-	65,200	-	1
At 5.5 ft.	.714	"	3029	-	84,200	-	1

TABLE IV-B - Homogeneous Plate

1/4" None	.250	.30	1191	-	44,000	-	1
At 4'	.339	"	2767	406	87,200	14,000	2
At 5.5'	.339	.50	1573	-	63,500	-	1
1/2" None	.500	.50	1344	-	44,600	-	1
At 5.5'	.589	"	2913	179	89,450	5,450	2
1" None	1.00	.50	2393	-	56,250	-	1
At 5.5'	1.09	"	3180	-	72,000	-	2

* Probable error of average.

(42)

Table V-A Comparison of Screened Face Hardened Plate and Face

Plate Thick. Inches	Tipping Screen	Equiv. Proj. Thick. Screened Plate	Cal. Bullet	Hardened Plate at Normal			Weight Saving Due to Screen, %	Limit Vel. F.H. Plate Same as Screen, %	Limit Vel. F.H. Plate Same thick due to Screen	%Inc. in Energy Req.
				Average Limit Velocity	Thick. Plate Same Limit Vel.	F.H. Same Limit Vel.				
1/4"	Angle 45° at 5.5'	.313"	.30	2419	.395"		21.1%	2200.		21.1%
1/4"	At 4'	.339"	.30	2689	.456"		26.1%	2250.		43.1%
1/4"	At 5.5'	.339"	.30	2608	.440"		23.1%	2250.		34.1%
1/4"	At 5.5'	.339"	.50	1465	*.265"		*-28.1%	*1990.		-46.1%
5/8"	At 5.5'	.714"	.50	3029	*.21"		*29.1%	2450.		53.1%

* Minus sign indicates loss for tipping screen combination

** This value obtained from well known results of numerous firings against 1" F.H. plate.

† Extrapolation doubtful due to lack of sufficient data for caliber .50 bullets at these thicknesses.

Table V-B Comparison of Screened Homogeneous Plate and Similar

<u>Homogeneous Plate at Normal</u>									
Plate Thick Inches	Tipping Screen	Equiv. Proj. Thick. Screen Plate	Cal. Bullet	Aver. Limit Velocity	Thick. Hom. Plate Same Limit Vel.	Weight Saving Due to Screen, % Same thick.	Limit Vel. Hom. Plate	% Inc. in Energy Req. Due to Screen	
1/4"	At 4'	.339"	.30	2767	.685"	50.1%	1630.	183.1%	
1/4"	At 5.5'	.339"	.50	1573	.625"	46.1%	*1100.	104.1%	
1/2"	At 5.5'	.589"	.50	2913	1.27"	53.1%	1500	280.1%	
1"	At 5.5'	1.09"	.50	3180	1.30"	16.1%	2600	50.1%	

* Extrapolation doubtful due to lack of sufficient data for caliber .50 bullets at these thicknesses.

Table VI-A Comparative Characteristics of Tipping Screens Producing a Yaw of

35° For Caliber .50 Bullets. Required Distance Behind Screen For

Obtaining of Yaw Indicated

Screen Material	Actual Thickness Screen	Angle of Obliquity	Total Equiv. Proj. Thick.†	*Distance in ft. behind Screen Required for		Deviation Min.-Max. Δ
				Average	Minimum Maximum	
24ST Duraluminum	.125"	40°	.058"	4.8'	4.0	5.8'
		60°	.089"	2.3'	1.8'	3.2'
Mild Steel 1	.0475"	40°	.062"	7.0'	6.1'	9.5'
		20°	.101"	5.8'	4.6'	8.0'
		40°	.124"	2.8'	2.4'	3.1'
		60°	Jacket stripped, erratic behavior			
Mild Steel 2	.063"	60°	.126"	1.4'	1.0'	2.0'
		60°	.150"	1.3'	1.0'	1.6'
"Cor-Ten" 2	.075"	60°		(approx.)		.3'

* Distances indicated were obtained from yaw vs. distance behind screen curves, about 5 of which

were used to characterize given screen behavior Average distance corresponds to average of

yaw vs. distance curves Minimum distance corresponds to maximum envelope of yaw vs. distance

curves Maximum distance corresponds to minimum envelope of yaw vs. distance curves and is one that would

be recommended in practice.

† Reduced to equivalent weight of steel plate in all cases.

1 From data of B. W. Report No. 220.

2 From data of Appendix B.

Table VI-B Comparative Characteristics of Composite "Sandwich" Screens (of Carnegie

Illinois) Producing a Yaw of 35° for caliber .50 Bullets. Required Distance Behind

Screen for obtaining of Yaw Indicated.**

Plate	Tipping Screen Construction	* Equiv. Thick. Screen	Angle of Obliquity	Total Equiv. Projected Thick, In.	Distance Ft# behind Screen for Average
15B2	.045", 1070Mo ¹ -1/2" Airfoam-.145", 1070W ¹ , Rc.45	.090"	45°	.127	1.8'
16B2	" " " " " "	"	"	"	2.3'
10F1	.062", NiCr ² -1/2" Airfoam-.062", NiCr ² , Rc.27	.124"	45°	.175	1.1'
12F1	" " " " Rc.45	.124"	45°	.175	.8'
7B1	.075", 1070Mo ¹ -1/2" Airfoam-.075", 1070Mo ¹ , Rc.45	.150"	20°	.160	1.3'

** Determined, from results furnished in letter of Watertown Arsenal to Chief of Ordnance, dated May 27, 1941.

* Distance indicated corresponds to average of yaw vs. distance curves obtained from 5 rounds.

Total thickness of steel components of tipping screen, weight of rubber airfoam being neglected.

1 S. A. E. - 1070 with Moly.

2 Fine-grained nickel-chrome steel.

Table VII-A. Comparison of Screened Homogeneous Plate and Similar Homogeneous

Plate at Optimum Obliquity												
Plate Tipping Thick screen	Equiv. Proj. Thick. screen	Cal. Bullet	Average Limit Velocity	Hom. Plate same Limit Vel.*			Weight Saving %	Limit Vel. Hom. Plate Same Equiv. Thick.		% Inc. in Energy Req. due to Screen		
				Ip	Ta	θ		V	Ta		θ	
1/4" At 4'	.339"	.30	2767	.370"	1/4"	47 1/2°	8.4%	2400	1/4"	42 1/2°	33.6	
1/4" At 5.5'	.339"	.50	1573	.327"	1/4"	40°	-4.0%	1630	1/4"	42 1/2°	-7.0%	
1/2" At 5.5'	.589"	.50	2918	.710"	1/2"	45°	17.6	2490	1/2"	32°	37.6	

Table VII-B. Comparison of Screened Homogeneous Plate and Best Homogeneous Plate

(of Higher Hardness than that Employed in Screened Plate Tests) at

Optimum Obliquity.

1/4"	At 4'	.339	.30	2767	.350"	1/4"	44 1/2°	3.1%	2700	1/4"	42 1/2°	5.0%
1/4"	At 5.5'	.339	.50	1573	.327"	1/4"	40°	-4.0%	1650	1/4"	42 1/2°	-9.0%
1/2"	At 5.5'	.589	.50	2918	.615"	1/2"	35 1/2°	4.2%	2750	1/2"	32°	13%

* Note that insufficient data were available to obtain optimum thickness and obliquity of
of homogeneous plate for .30 bullets.

Ta is actual thickness of homogeneous plate

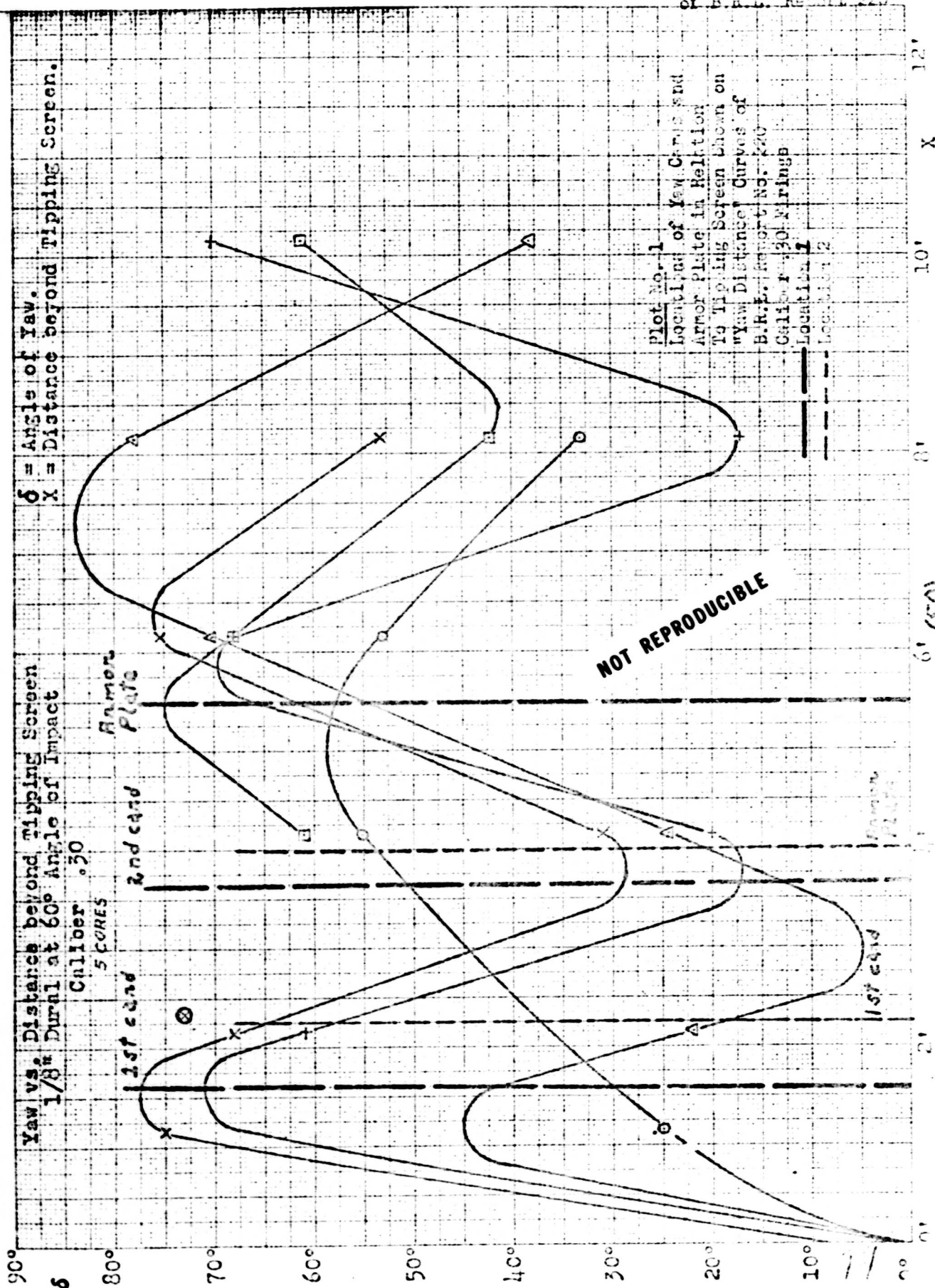
Tp is equivalent projected thickness of plate $= \frac{T_a}{\cos \theta}$

θ is angle of obliquity of plate

Plots to Accompany

Ballistic Research Laboratory Report No. 249

Figure 57
 of B.R.L. Report 220



Yaw vs. Distance beyond Tipping Screen
1/8" Dural at 60° angle of impact
Caliber .50

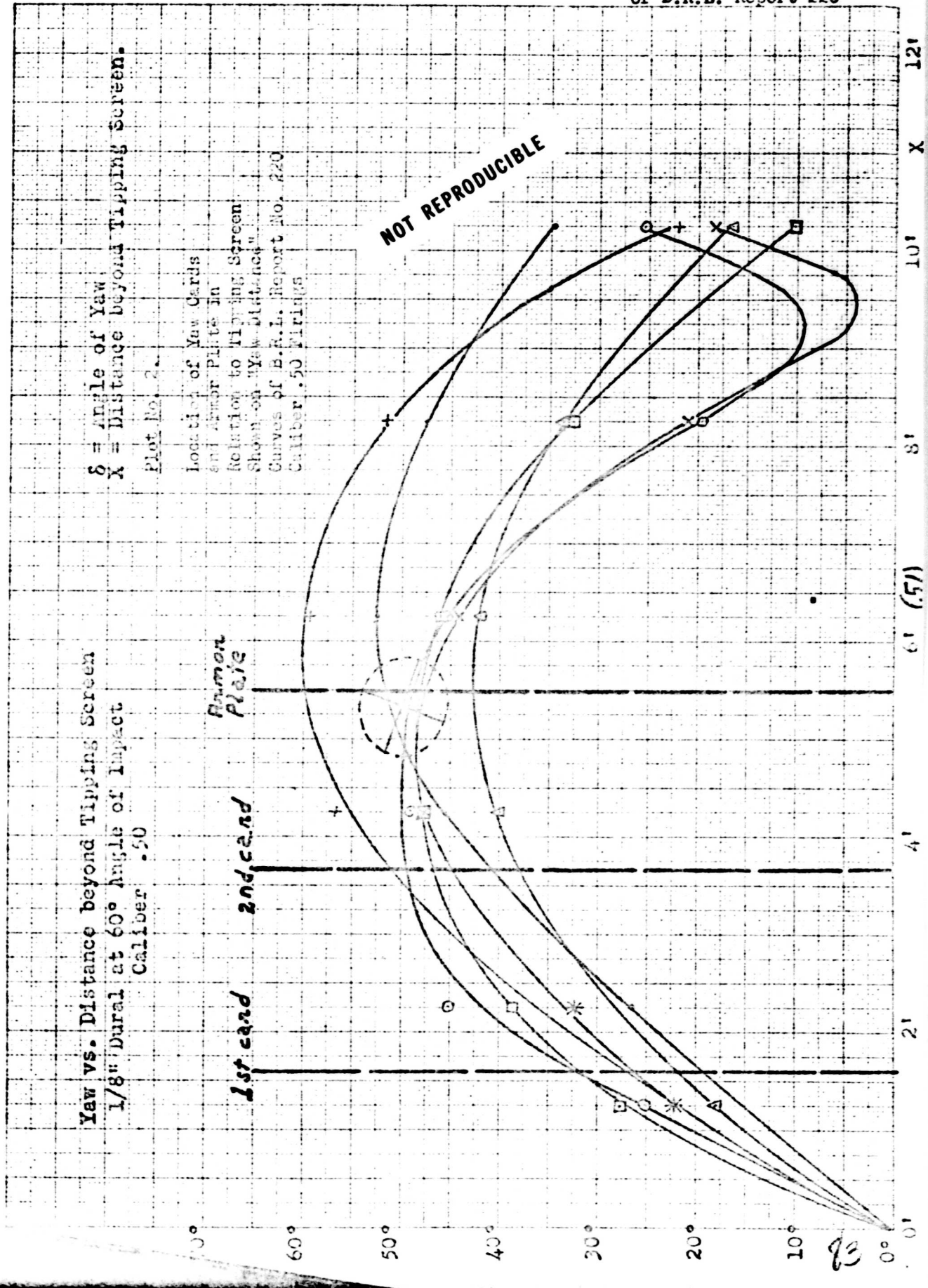
δ = angle of yaw
X = Distance beyond Tipping Screen.

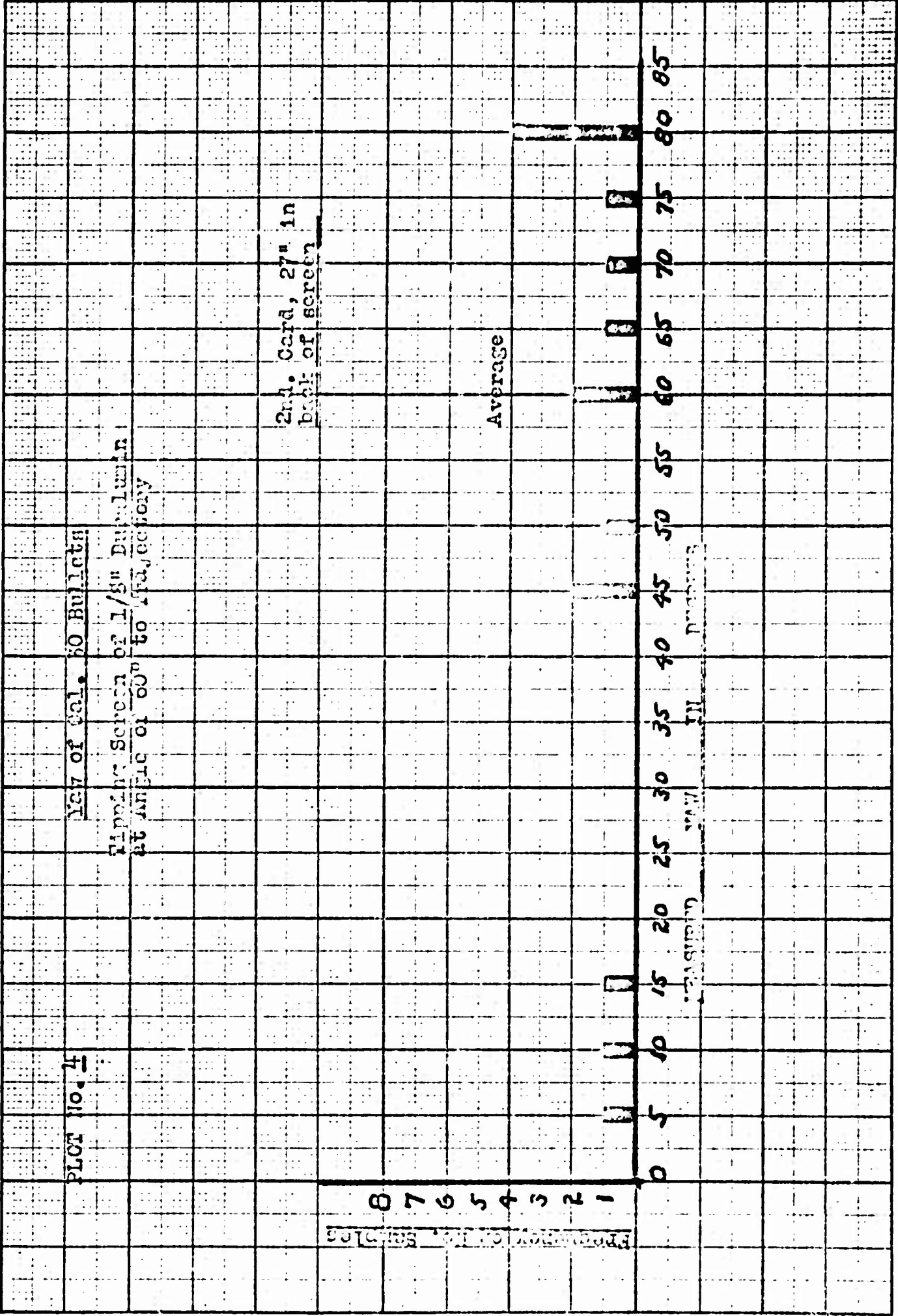
Plot No. 2.

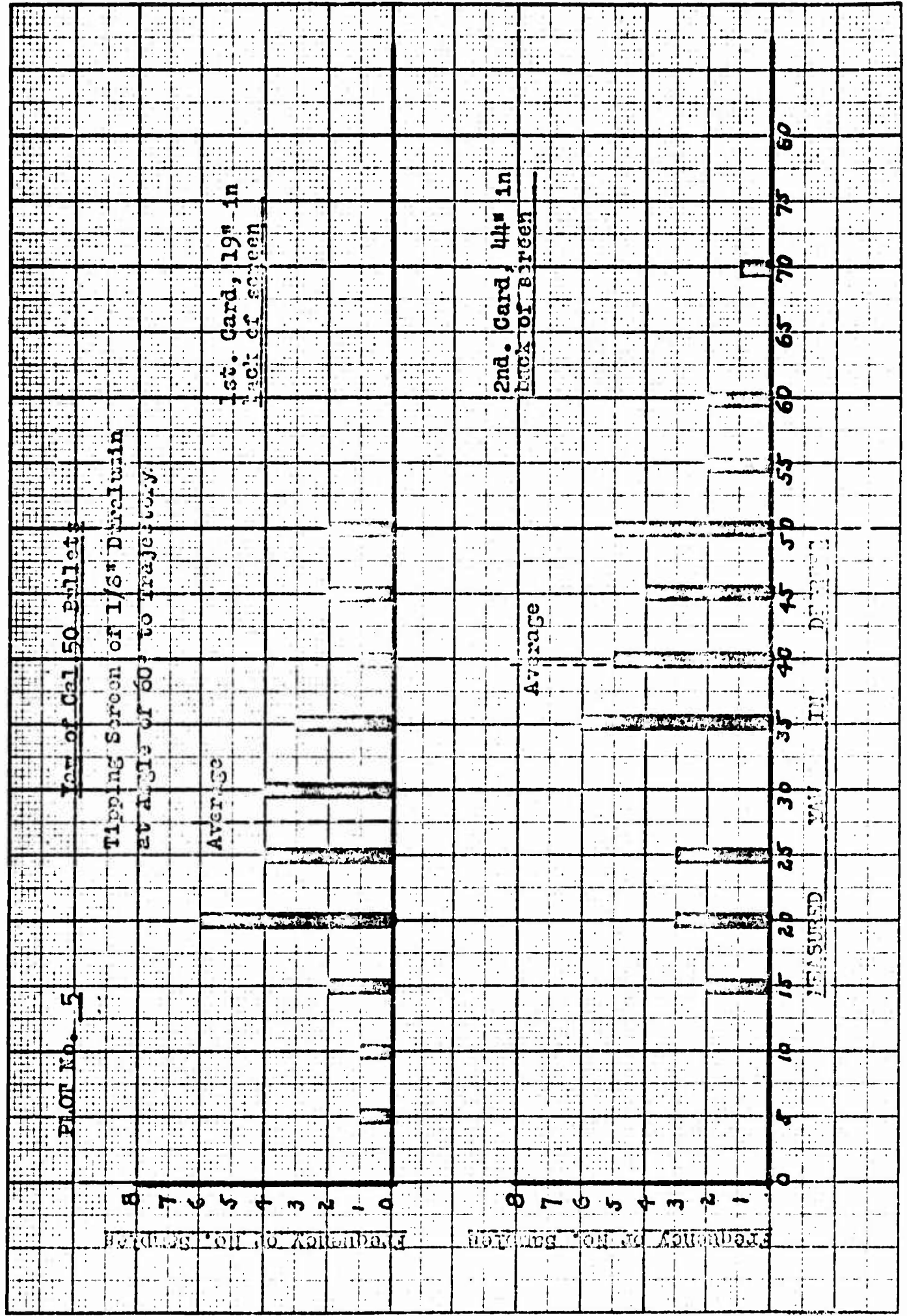
Location of Yaw Cards
and Tipping Plate in
Relation to Tipping Screen
Shown on "Yaw Distance"
Curves of B.R.L. Report No. 220
Caliber .50 Firings

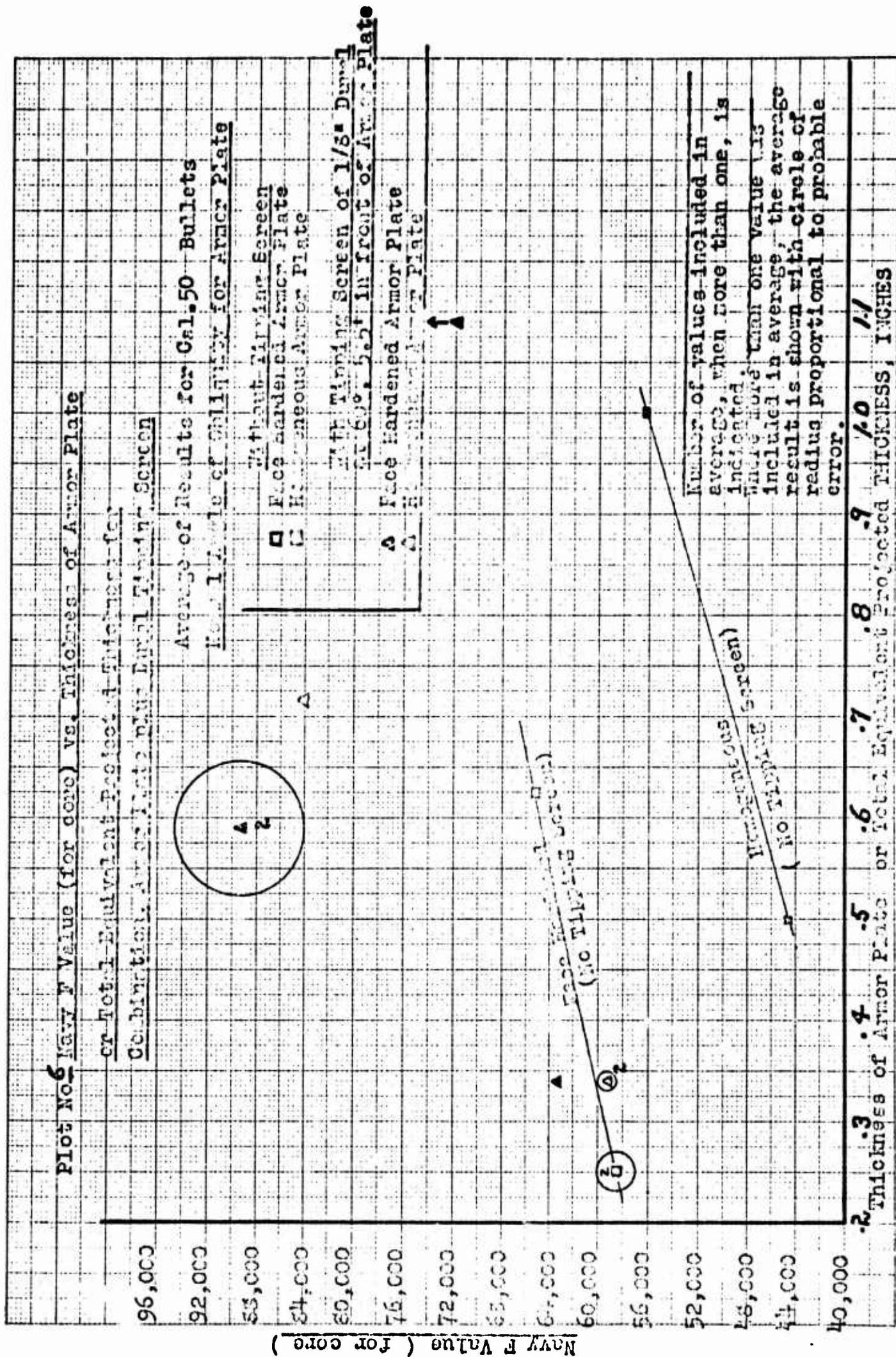
1st card
2nd card
Ramon
Plate

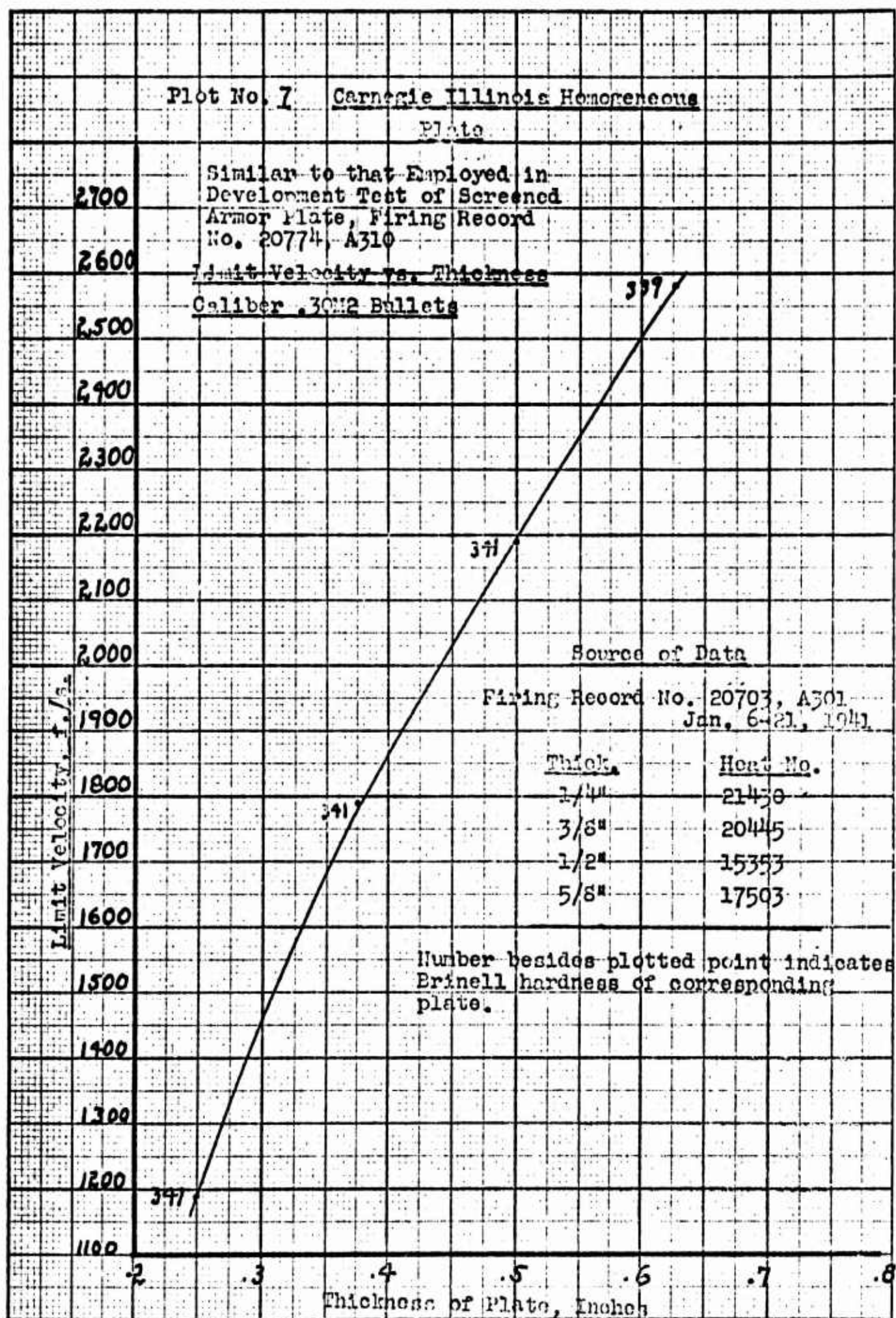
NOT REPRODUCIBLE











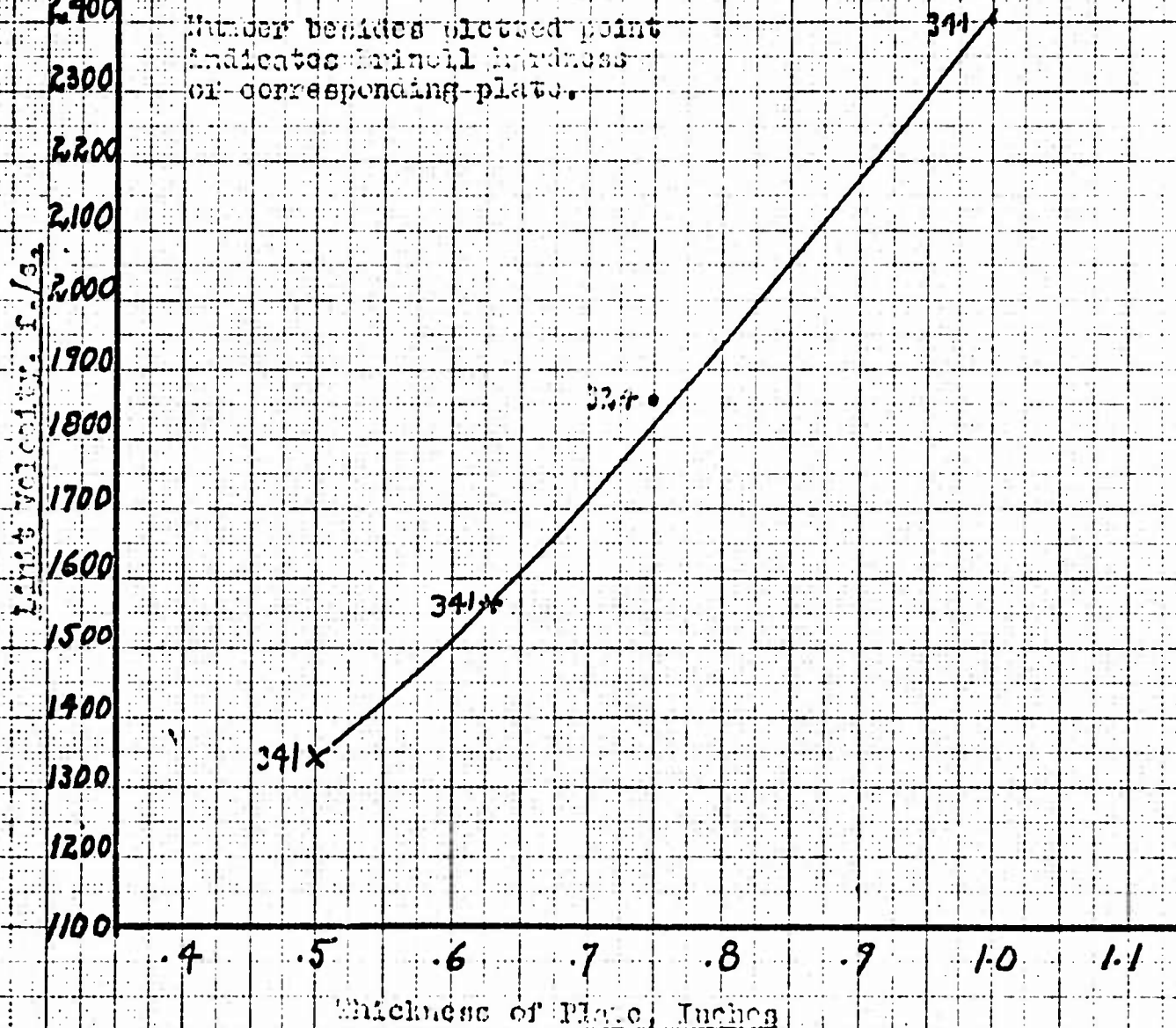
Plot No. 8 Carnegie Illinois Homogeneous Plate

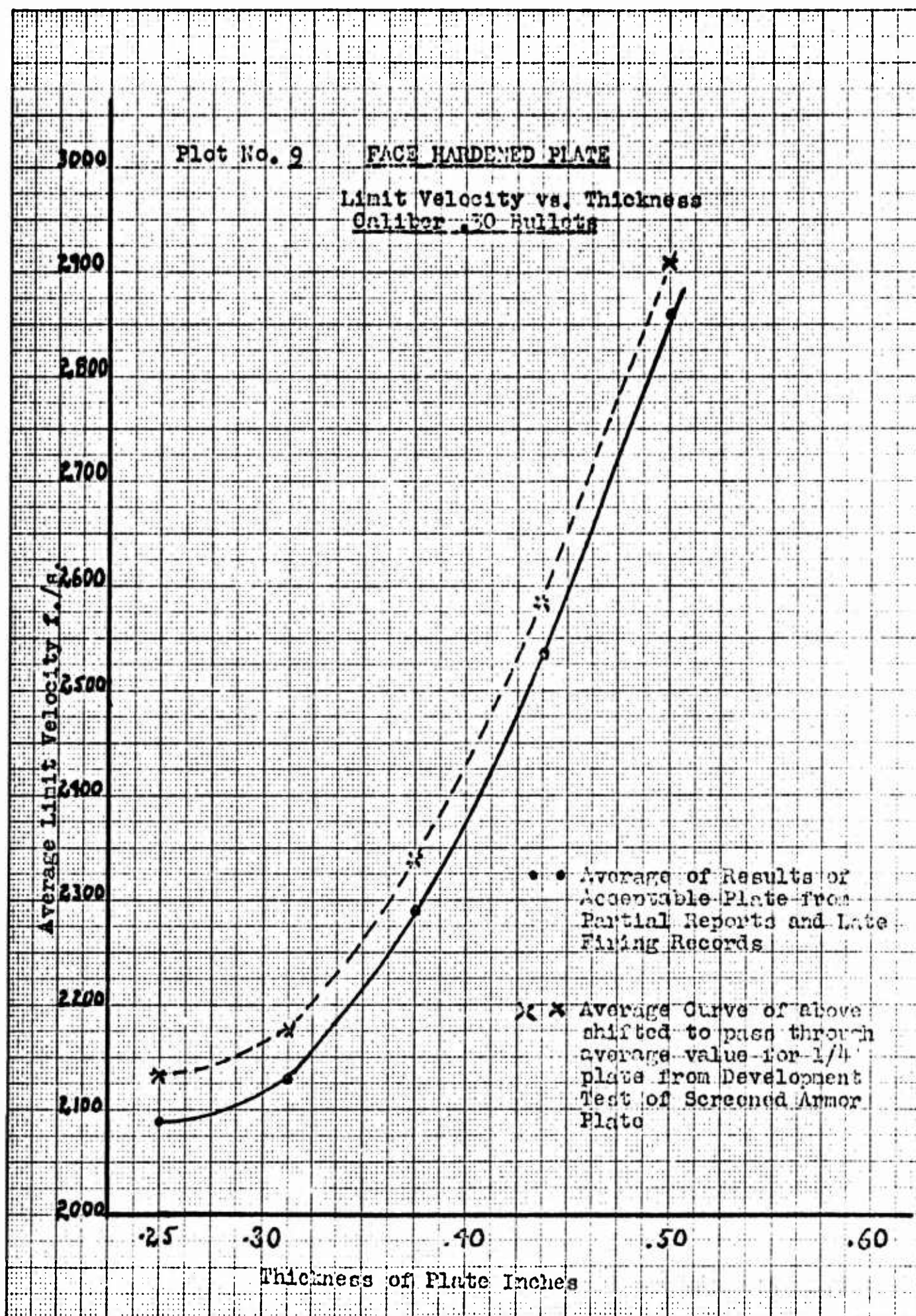
Similar to that Employed in Development
Test of Screened Armor Plate
Firing Record No. 20774, A310

Limit Velocity vs. Thickness
Caliber .50 Bullets

	Thickn.	Source Data.	Heat No.	Bullet Model
2700	1/2"	Firing Record	15353	M2
		20703, 301		
	5/8"	Jan. 6-21, 1941	17503	M2
2600	3/4"	Partial Report	15353	M1
		Armor Plate No.	15353	M1
2500	1"	300.		
		Dec. 9, 1940		

Number besides plotted point
indicates Brinell hardness
of corresponding plate.



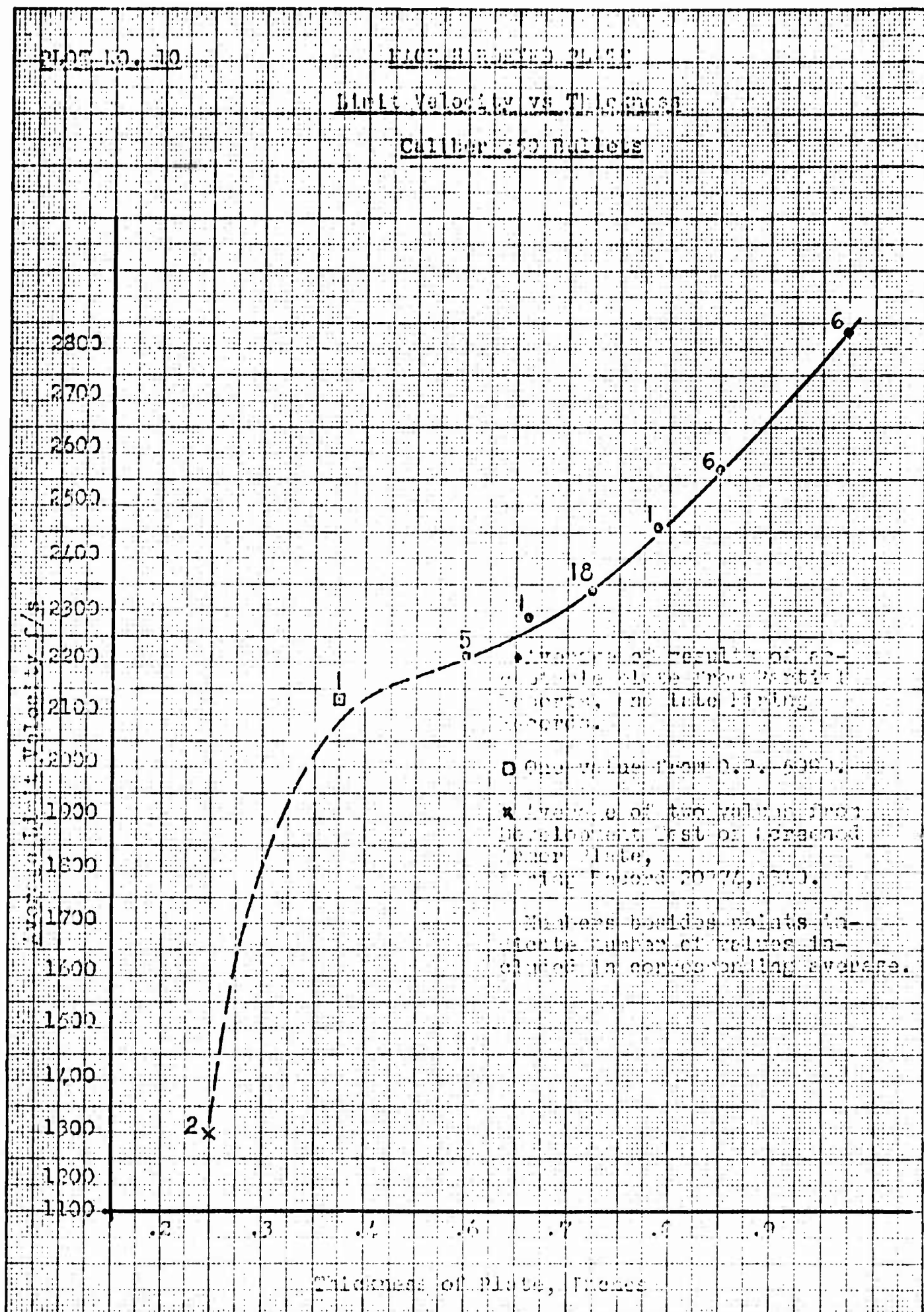


Plot No. 10

High Hardened Steel

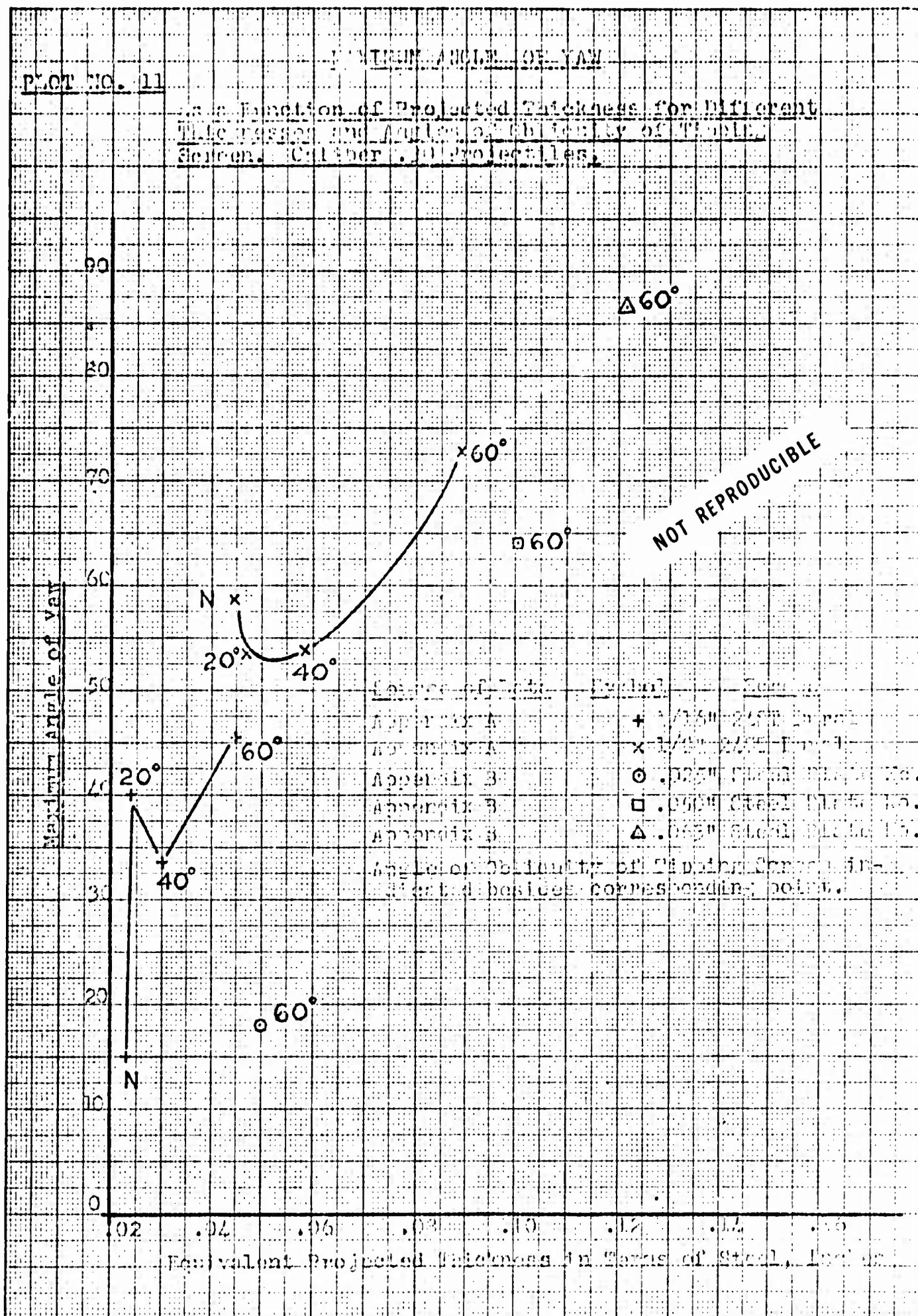
Limit Velocity vs Thickness

Caliber .50 Bullets



• Average of results of acceptable plate from partial shots, no late firing records.
 □ One value from O.P. 6990.
 x Average of two values from development test on cracked armor plate, firing record 70776, 70777.
 Numbers besides points indicate number of values included in corresponding average.

HEUFFEL & ESSER CO., N. Y. NO. 359-14
 Millimeters, inch lines heavy.
 MADE IN U.S.A.



Plot No. 12. MAXIMUM ANGLE OF VIEW AS A FUNCTION OF
PROJECTED THICKNESS FOR DIFFERENT THICKNESSES
AND ANGLE OF ORBITALITY OF TIPPING SCREENS

Source
 of
 Data

Cal. 50 Projectiles

Symbol Screen

Appendix A

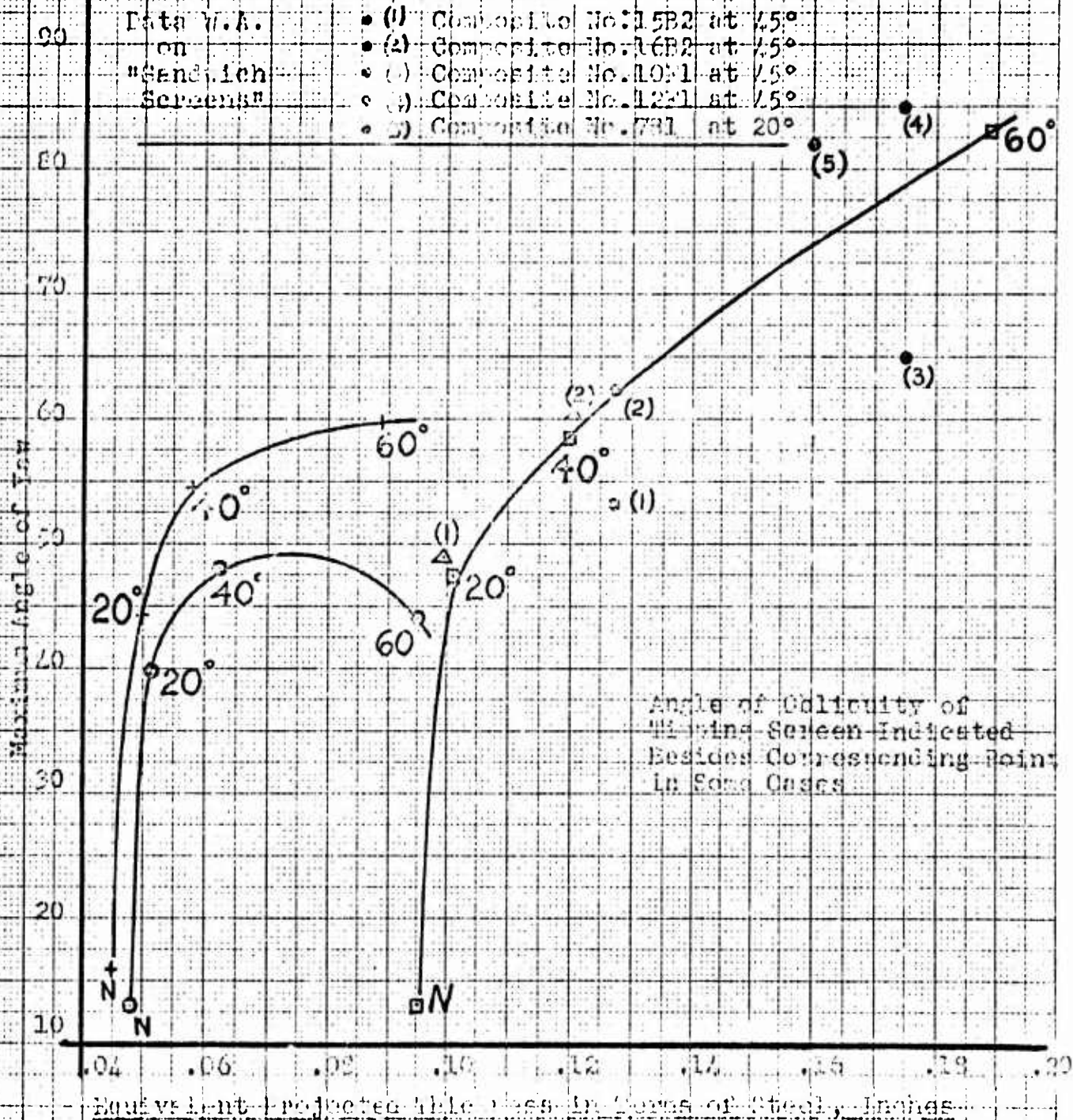
- + 1/8" 242T Dural
- x .0175" Mild Steel, SAE 1020
- .0051" Mild Steel, SAE 1020

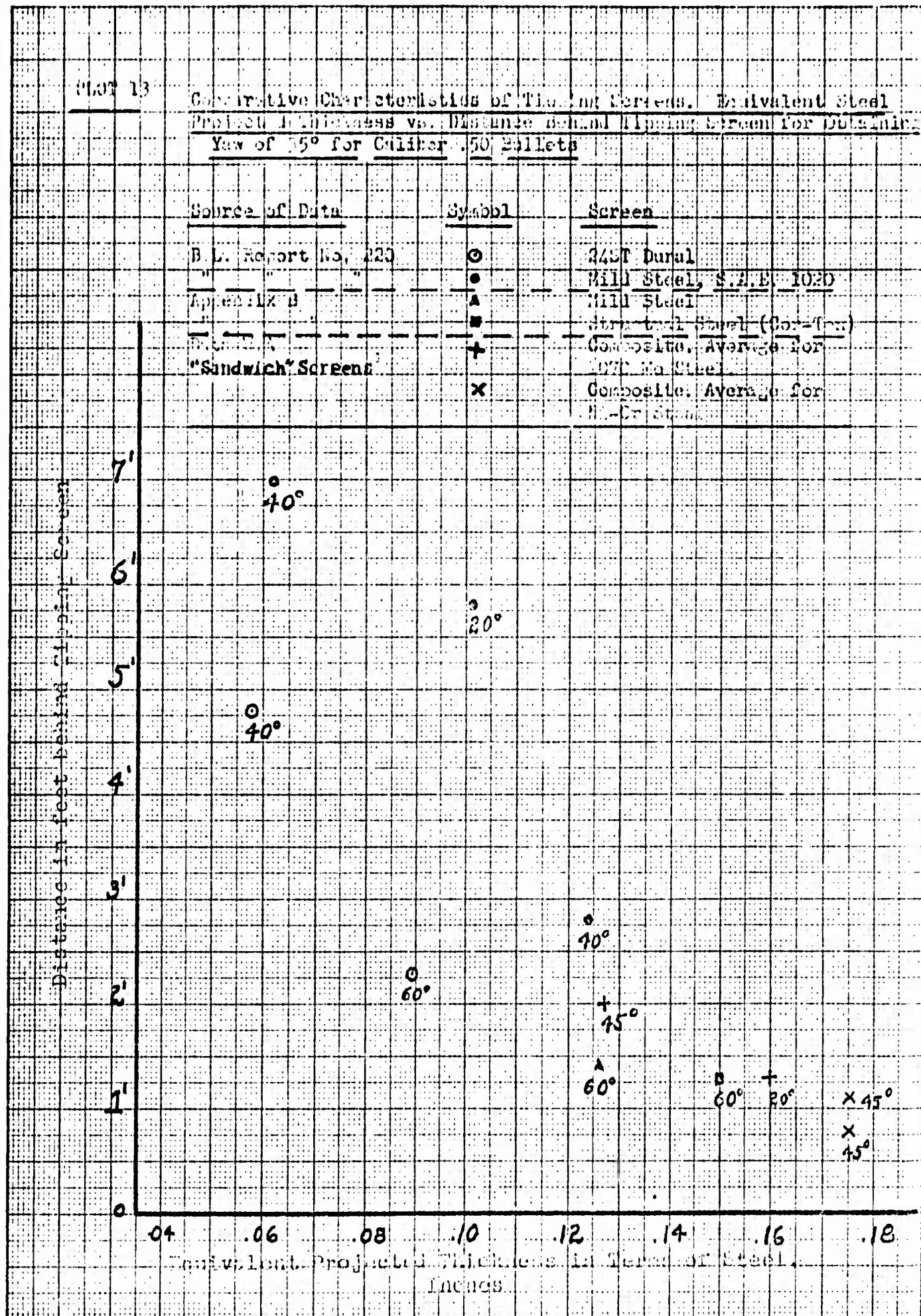
Appendix B

- $\Delta^{(1)}$.050" Steel Plate No. 49 at 60°
- $\Delta^{(2)}$.063" Mild Steel Plate No. 51 at 60°

Data W.A.
 on
 "Sandwich
 Screens"

- (1) Composite No. 15B2 at 45°
- (2) Composite No. 16B2 at 45°
- (3) Composite No. 10F1 at 45°
- (4) Composite No. 12F1 at 45°
- (5) Composite No. 7B1 at 20°





PLOT NO. 14

IMPACT VELOCITY VS. PROJECTED OR ACTUAL THICKNESS
 Carnotite-Illite Homogeneous Plate
 Cal. .30 M2 Bullets

00

Impact Velocity f/s

3200
3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000

.2

.3

.4

.5

.6

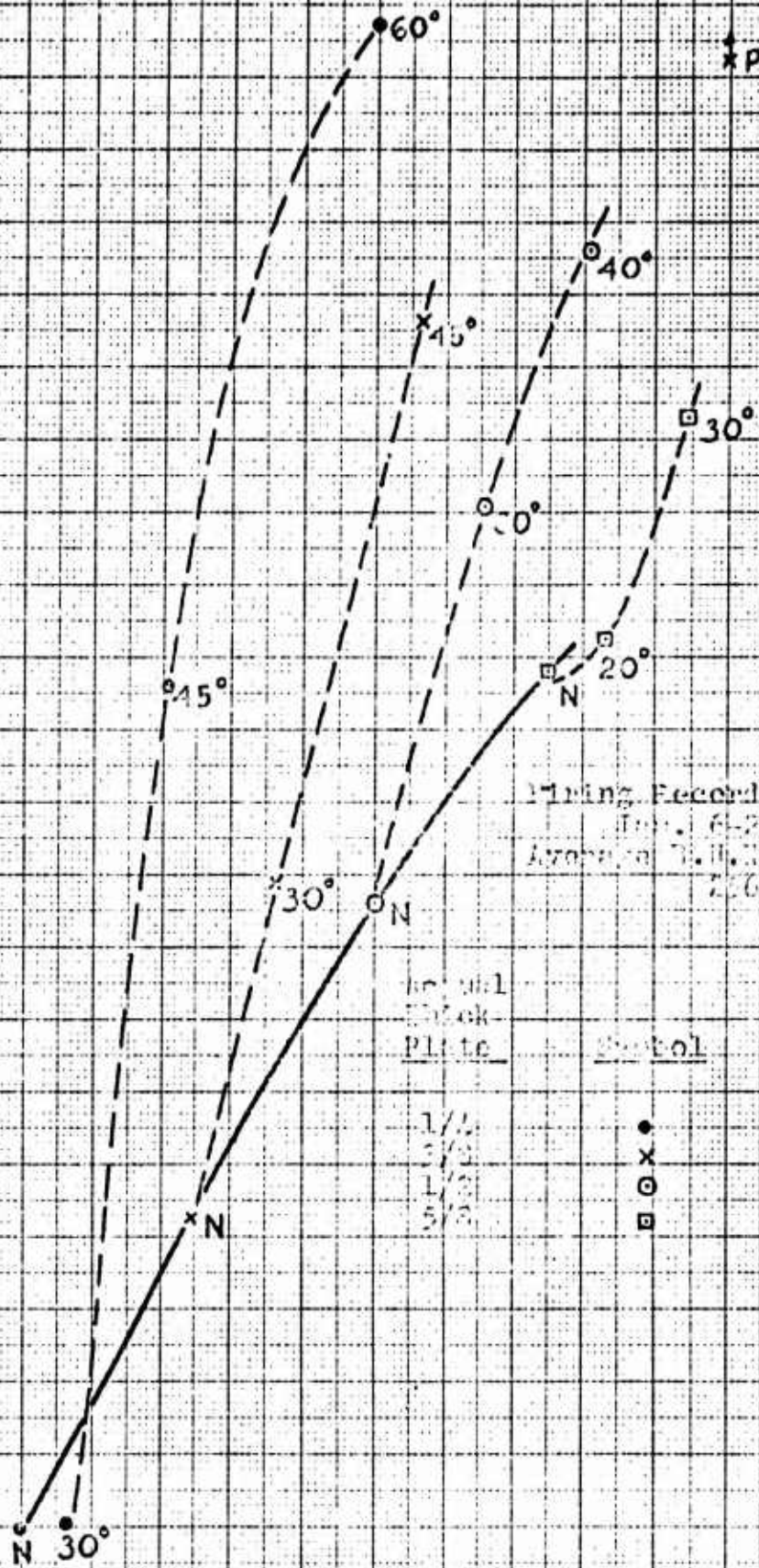
.7

.8

.9

Actual or Projected Thickness, Inches

(63)

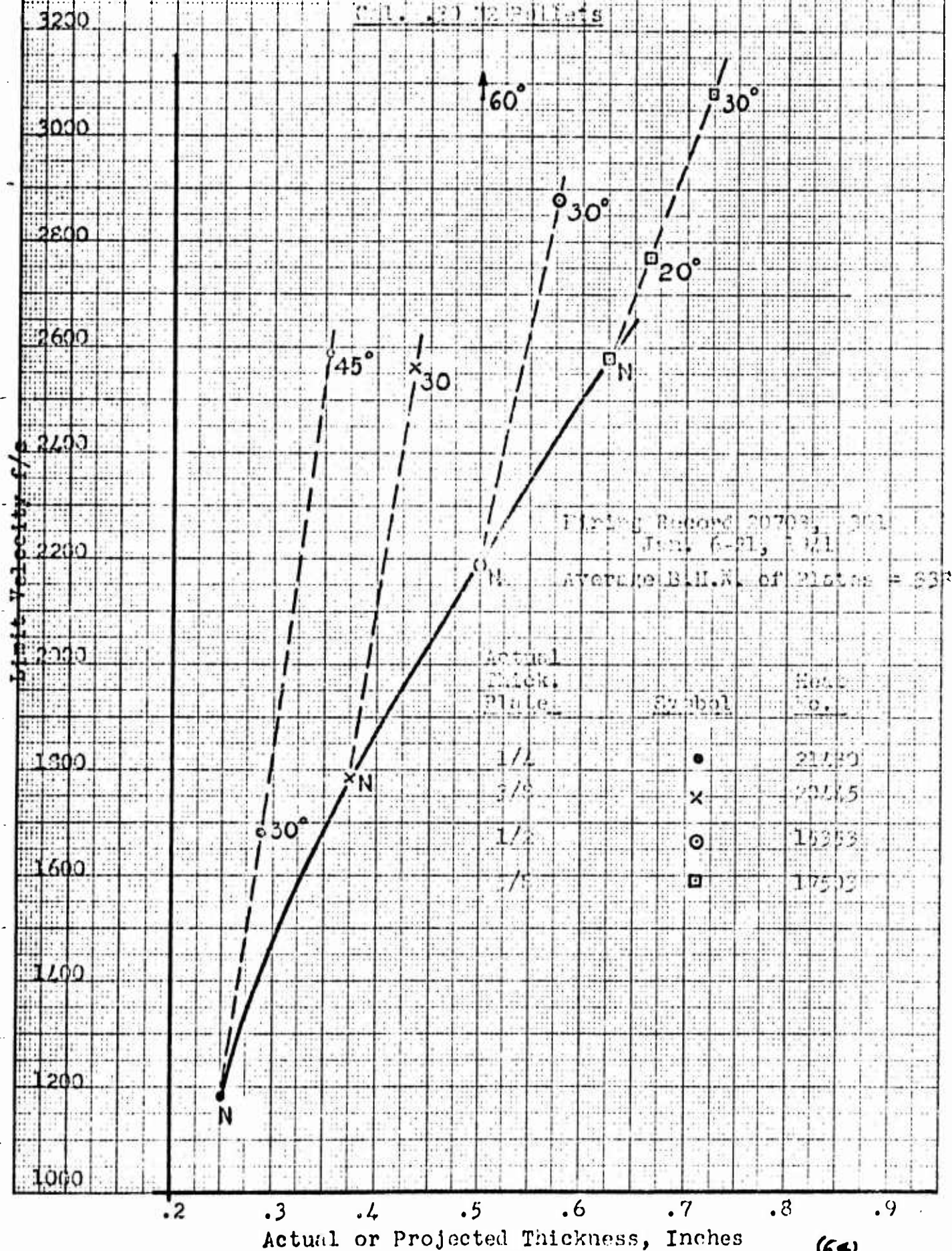


Firing Record 20712, 2101
 Test 6-21, 1941
 Average T.H.S. of plates = 200

PLOT NO. 15

PERMIT VELOCITY AS A FUNCTION OF PROJECTED OR ACTUAL THICKNESS

Carnegie-Illinois Homogeneous Plate
Y.L. 2012 Polaris

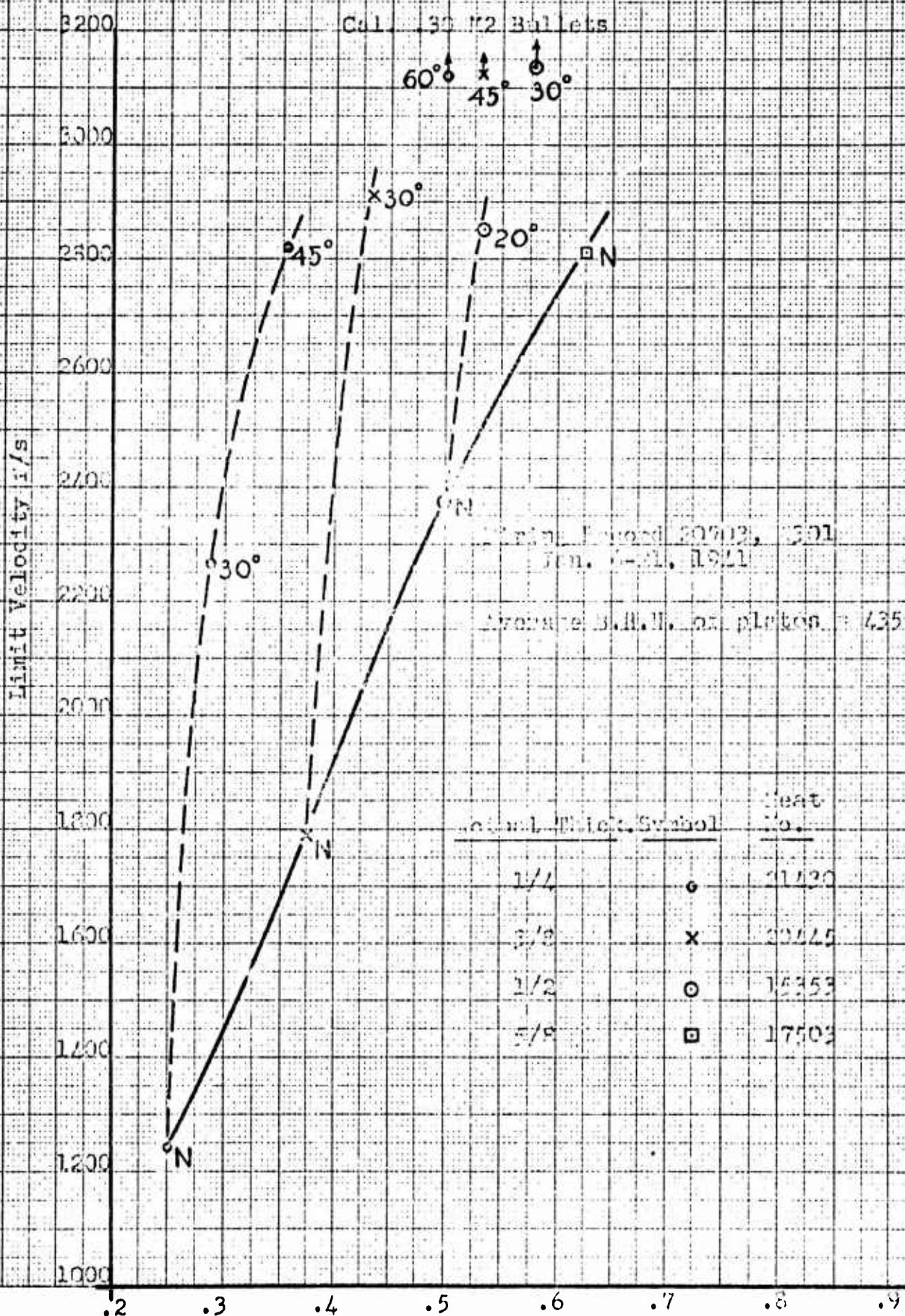


PLOT NO. 16

LIMIT VELOCITY AS A FUNCTION OF PROJECTED OR ACTUAL THICKNESS

Carnegie-Illinois Homogeneous Plate

Cal. .30 #2 Bullets



KEUFFEL & ESSER CO., N. Y. NO. 358-16
Millimeters, both lines heavy.
MADE IN U. S. A.

Actual or Projected Thickness, Inches

(65)

PLOT NO. 17

LIMIT VELOCITY AS A FUNCTION OF PROJECTED OR ACTUAL THICKNESS

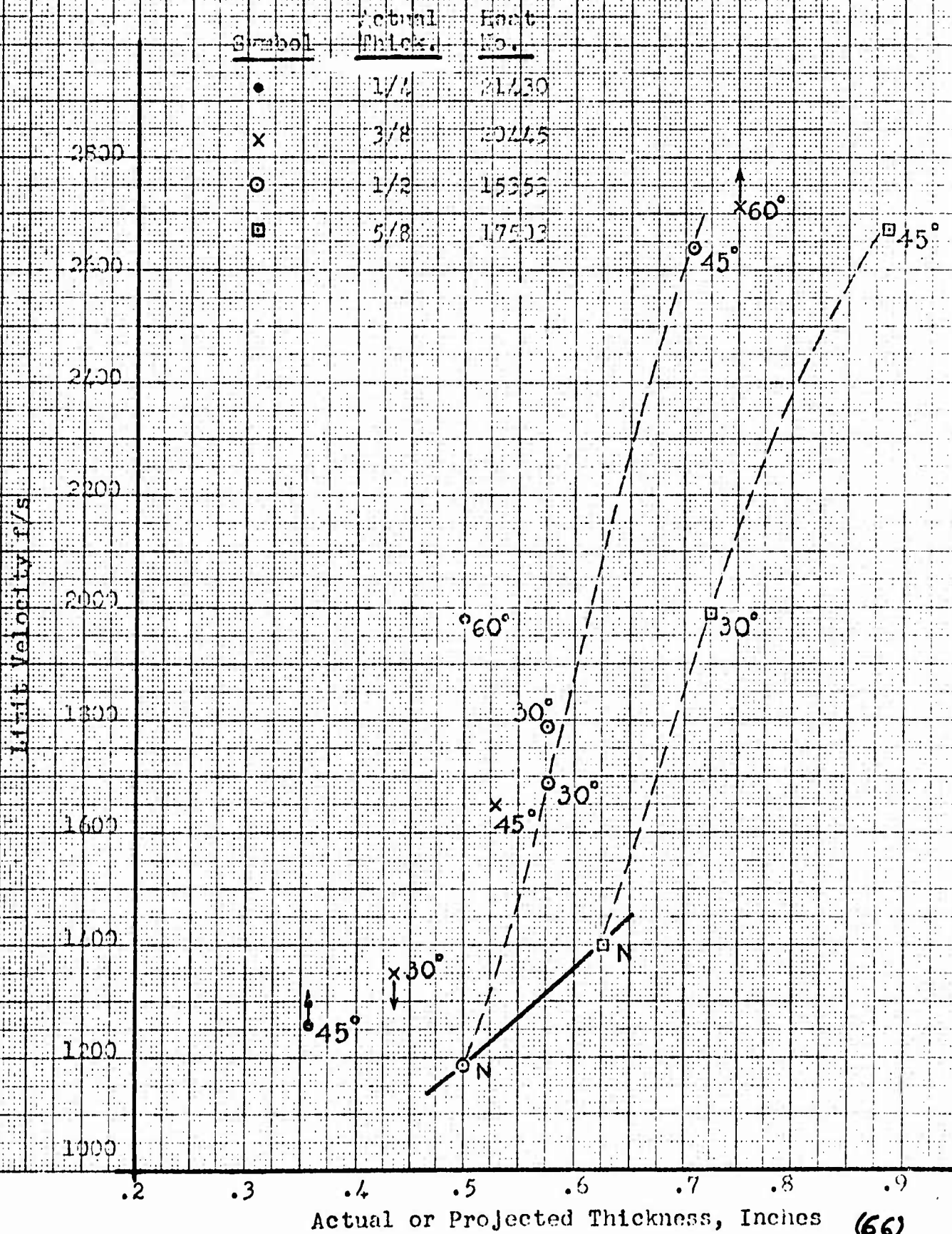
Chicago Illinois Homogeneous Plate

C. I. .50 M2 (71-79) Bullets

Firing Record 20703, A301

Jan. 6-12, 1921

Average B.H.N. of plates = 226



Plot No. 12 LIMIT VELOCITY AS A FUNCTION OF PROJECTED
OR ACTUAL THICKNESS

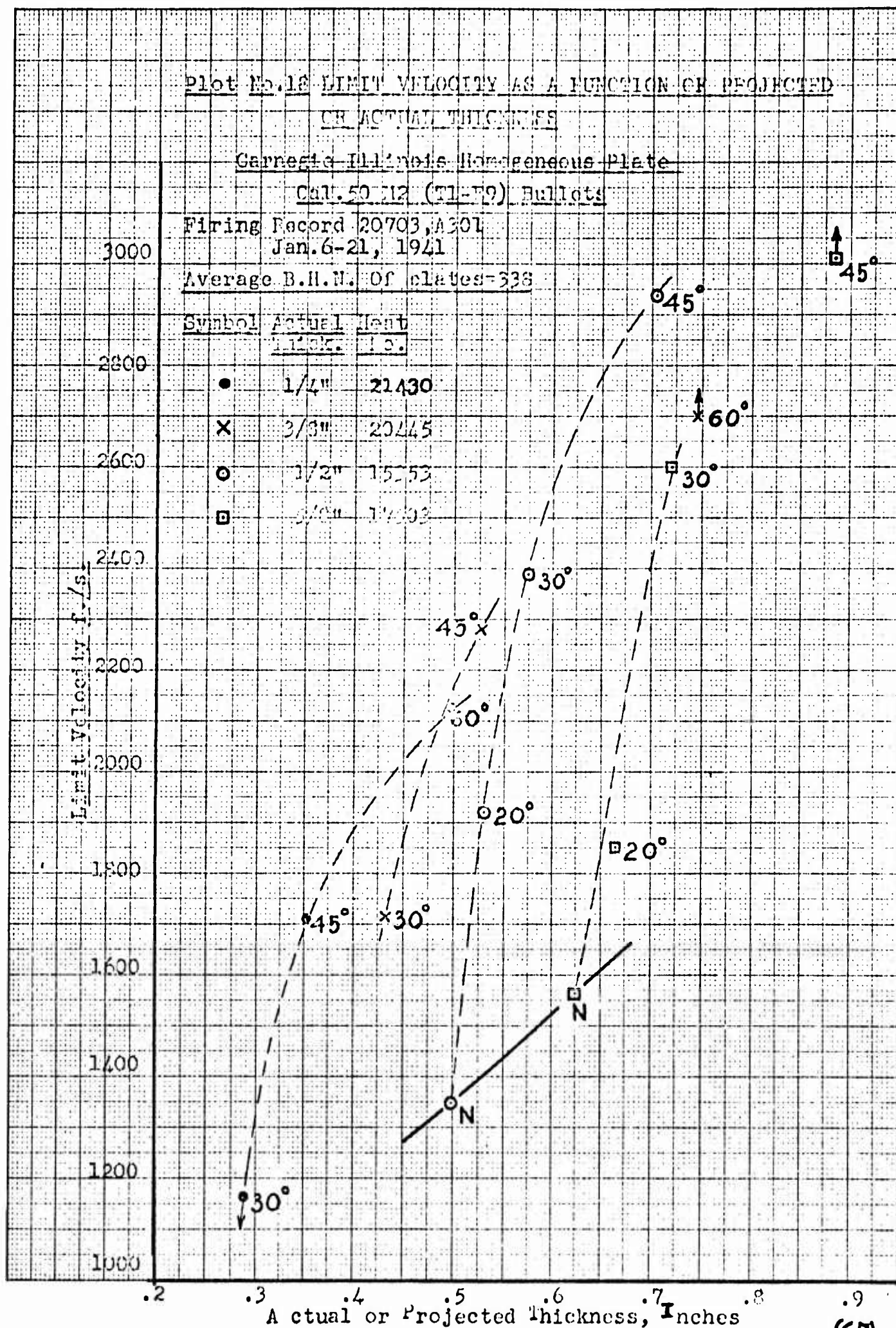
Carnegie-Indiana Homogeneous Plate

Cal. 50 M2 (T1-T9) Bullets

Firing Record 20703, A301
Jan. 6-21, 1921

Average B.H.N. Of plates = 538

Symbol	Actual Thick.	Limit V.
•	1/4"	21430
x	3/8"	20245
o	1/2"	15753
□	3/4"	14703



PLOT NO. 19

LIMIT VELOCITY AS A FUNCTION OF PROJECTED OR ACTUAL THICKNESS

Carnegie-Illinois Homogeneous Plate

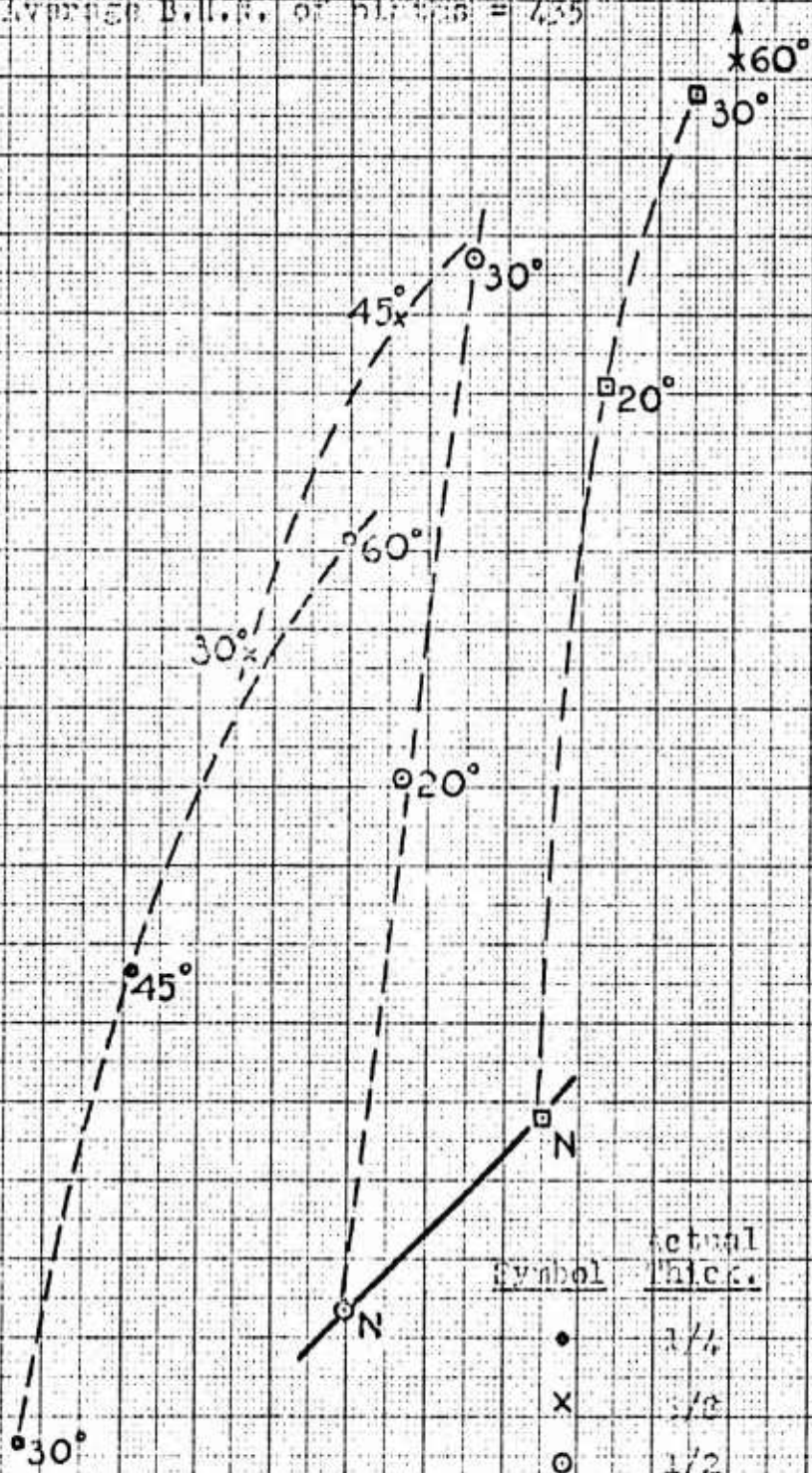
Cal. 7.62 FM-30 Bullets

Firing Record 20702, 1A201
Jan. 6-21, 1941

Average B.L.R. of plates = 435

Limit Velocity f/s

3000
2800
2600
2400
2200
2000
1800
1600
1400
1200
1000

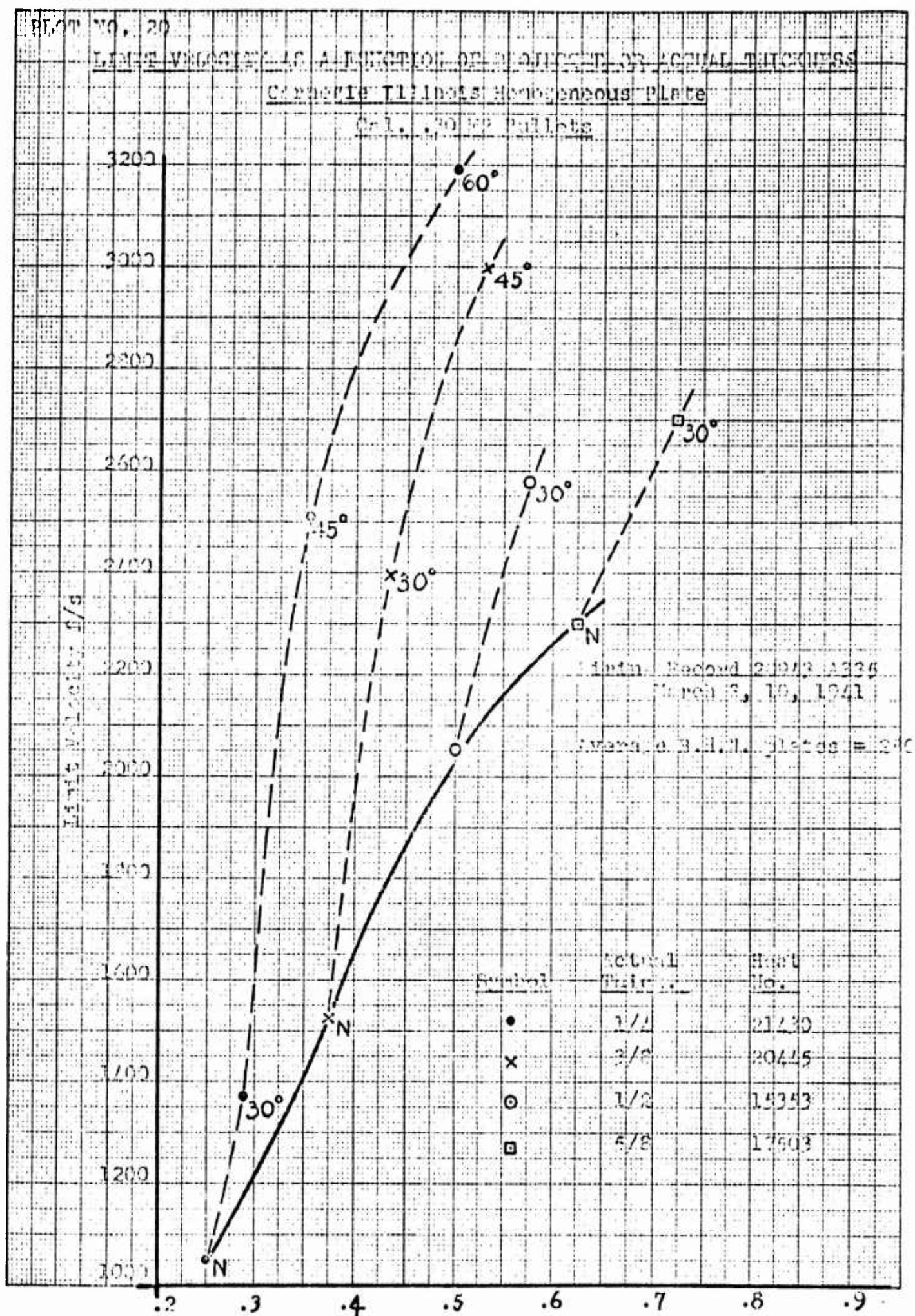


Symbol	Actual Thick.	Test No.
•	1/4	21750
x	1/2	20211
o	1/2	15353
□	5/8	17503

.2 .3 .4 .5 .6 .7 .8 .9

Actual or Projected Thickness, Inches

(68)



PLOT NO. 21

LIMIT VELOCITY AS A FUNCTION OF PROJECTED OR ACTUAL THICKNESS

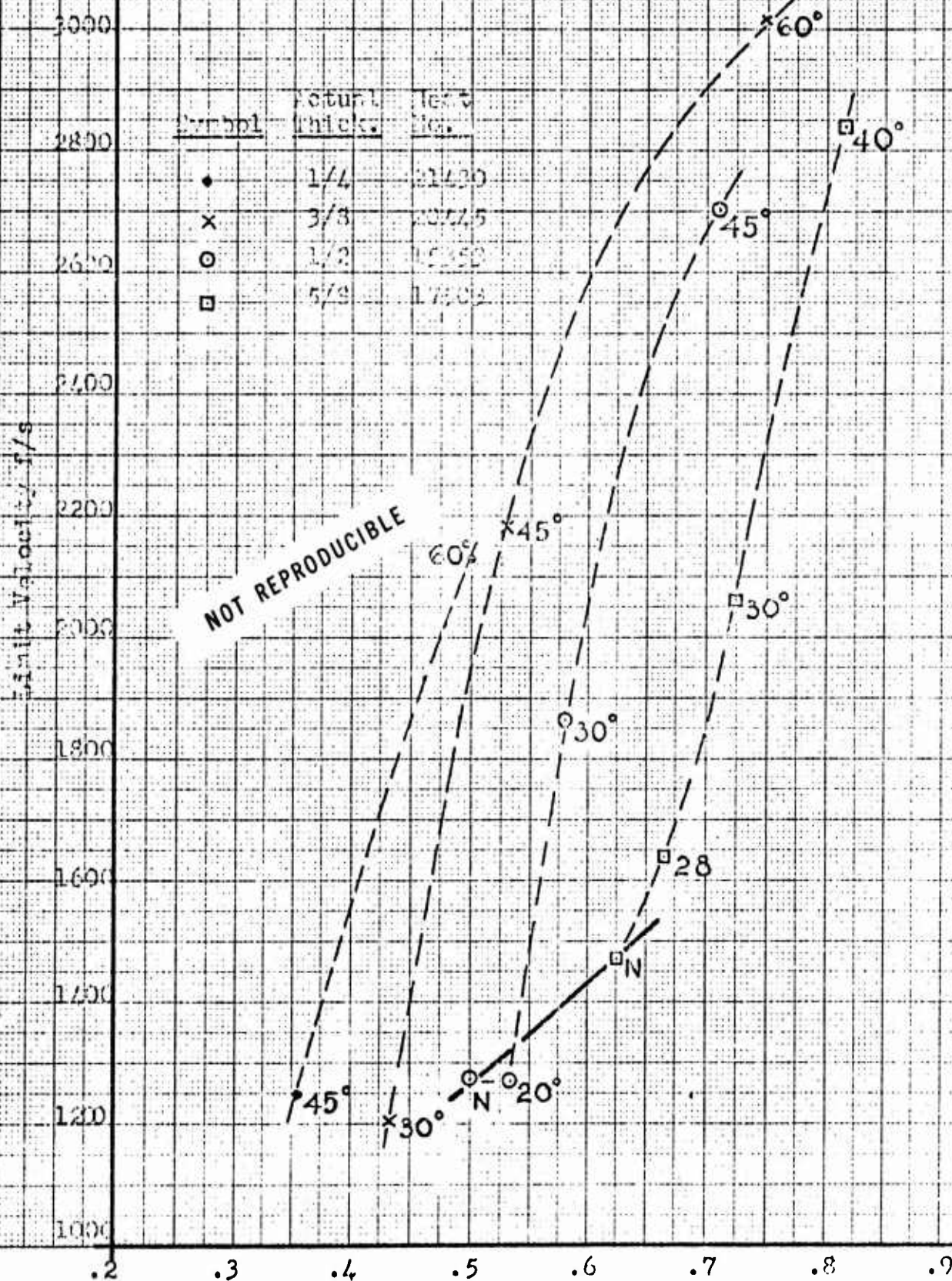
Cannado Blanks - Homogeneous Plates

Cal. .50 T (T1-E9) Bullets

Firing Record 20943, 1335

March 8, 1941

Average B.H.N. Plates = 280



Appendix A

Data on Tipping Screens
from

Ballistic Research Laboratory Report No. 220

Characteristics of Tipping Screens

Figure 70
of B.R.L. Report 220

PLOT 22

Effect of Angle of Impact

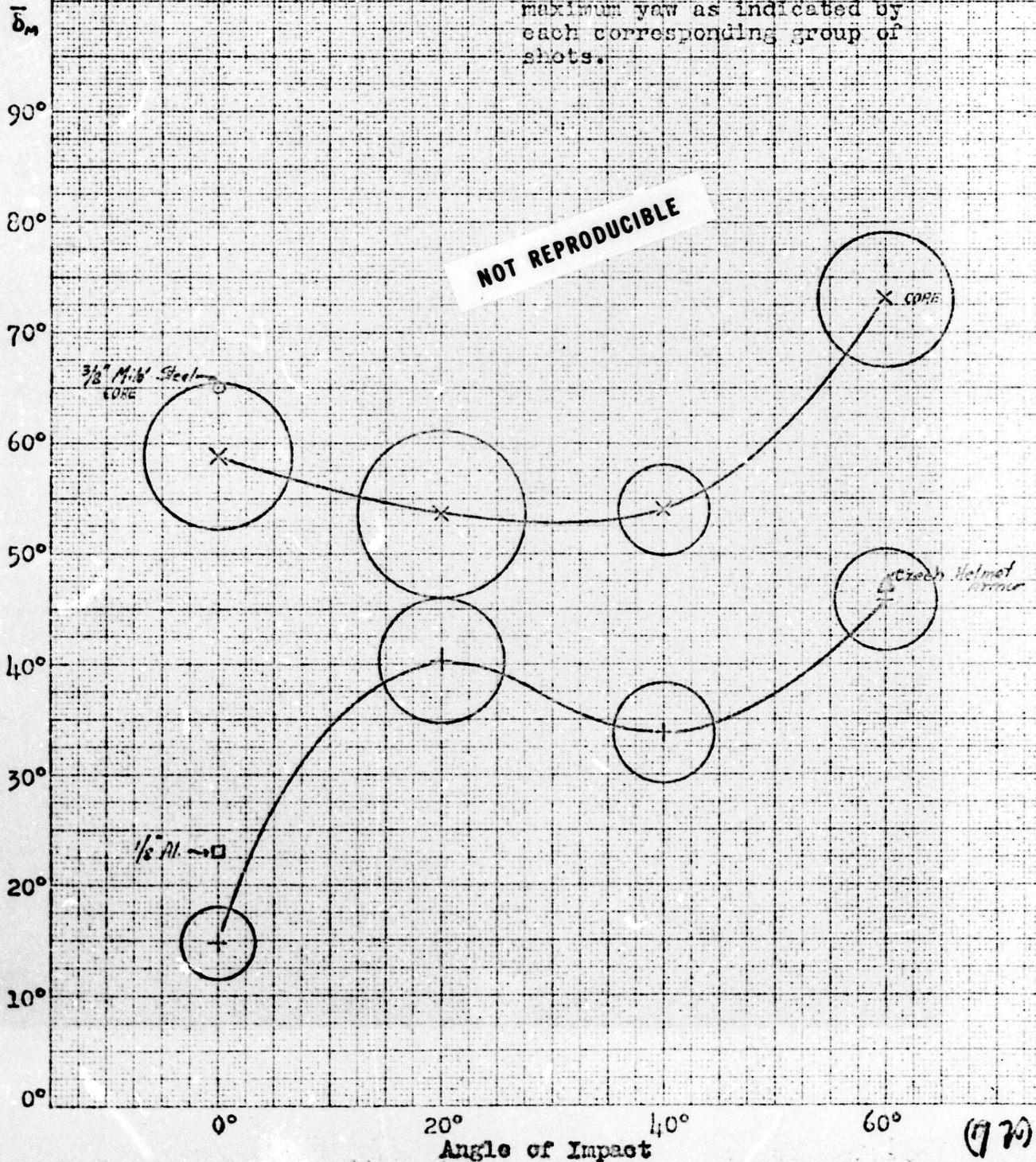
Caliber .30

$\bar{\delta}_m$ = Average first maximum yaw after penetrating tipping screen.

+ = 1/16" Dural.

x = 1/8" Dural.

Radius of circles are equal to the Probable Error in the first maximum yaw as indicated by each corresponding group of shots.



PLOT 23

Effect of Angle of Impact

Caliber .50

δ_m = Average first maximum yaw after penetrating tipping screen?

$t = 1/8"$ Dural.

$x = 0.0475"$ Steel.

$\square = 0.0451"$ Steel.

Radius of circles are equal to the Probable Error in the first maximum yaw as indicated by each corresponding group of shots.

δ_m

90°

80°

70°

60°

50°

40°

30°

20°

10°

0°

NOT REPRODUCIBLE

4 CORES

$1/8"$ Brass CORES

$1/8"$ Cu

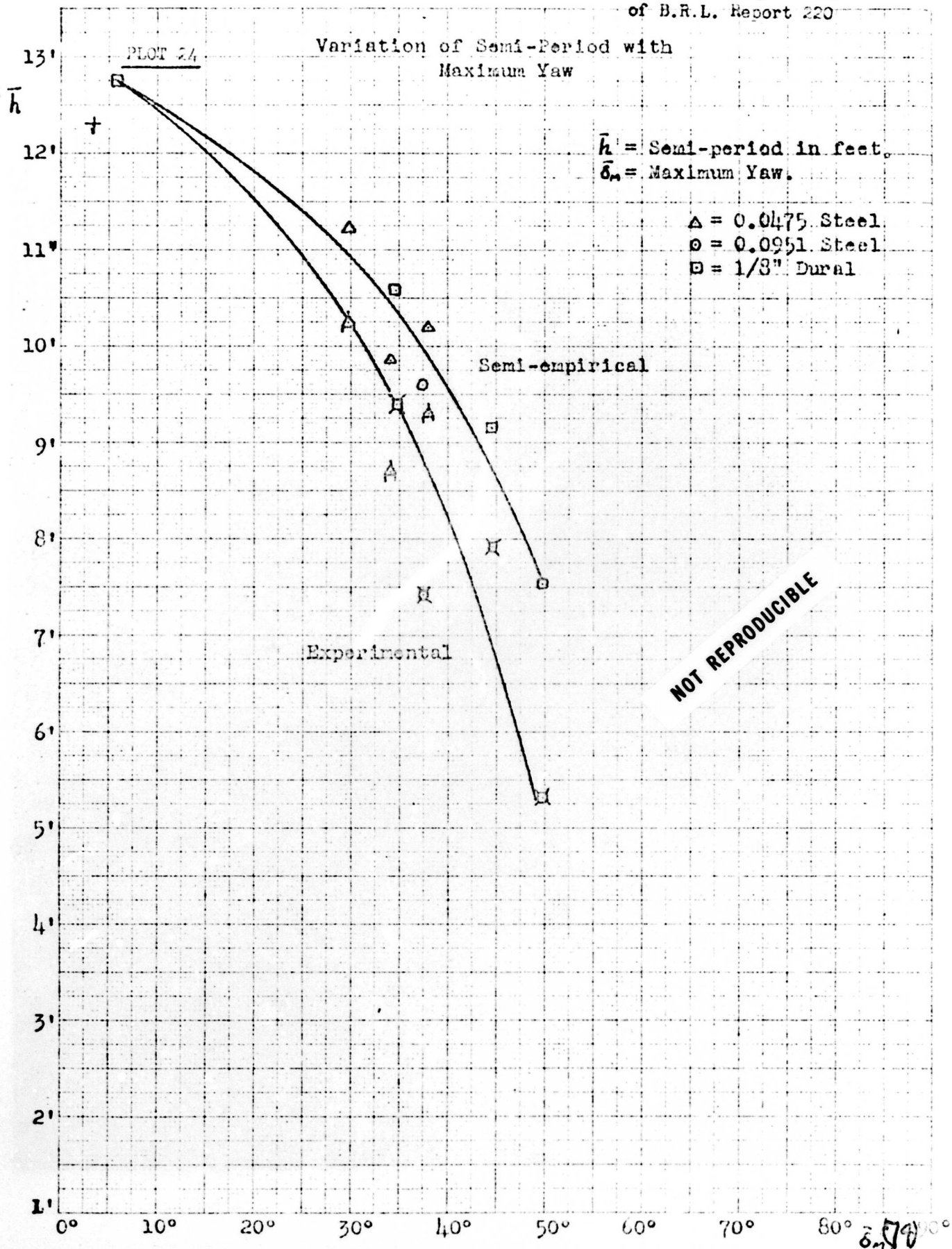
$1/8"$ Dural

Czech Helmet

$1/8"$ Al

Angle of Impact

(73)



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1954

Appendix B

Data on Tipping Screens Obtained by Proof Department
of APG, Firing Record 20703, A301

90°

Tipping Screen. Homogeneous Steel Plate No. 49
 .050" x 34" x 36"

Type 304, S.S. 1808 H1, Low Cc
 No heat treatment

Tensile Strength-- 150,000. p.s.i.

80°

Angle of Tipping Screen. 60°

Projectile. Cal. 30M2 A.P.

Rnd. Sym. Velocity

5

X

X

lost

6

□

□

lost

8

●

●

2547

Rnd. 7 core broke in
 two.

Angle of Vav. Degrees

70°

60°

50°

40°

30°

20°

10°

0

1'

2'

3'

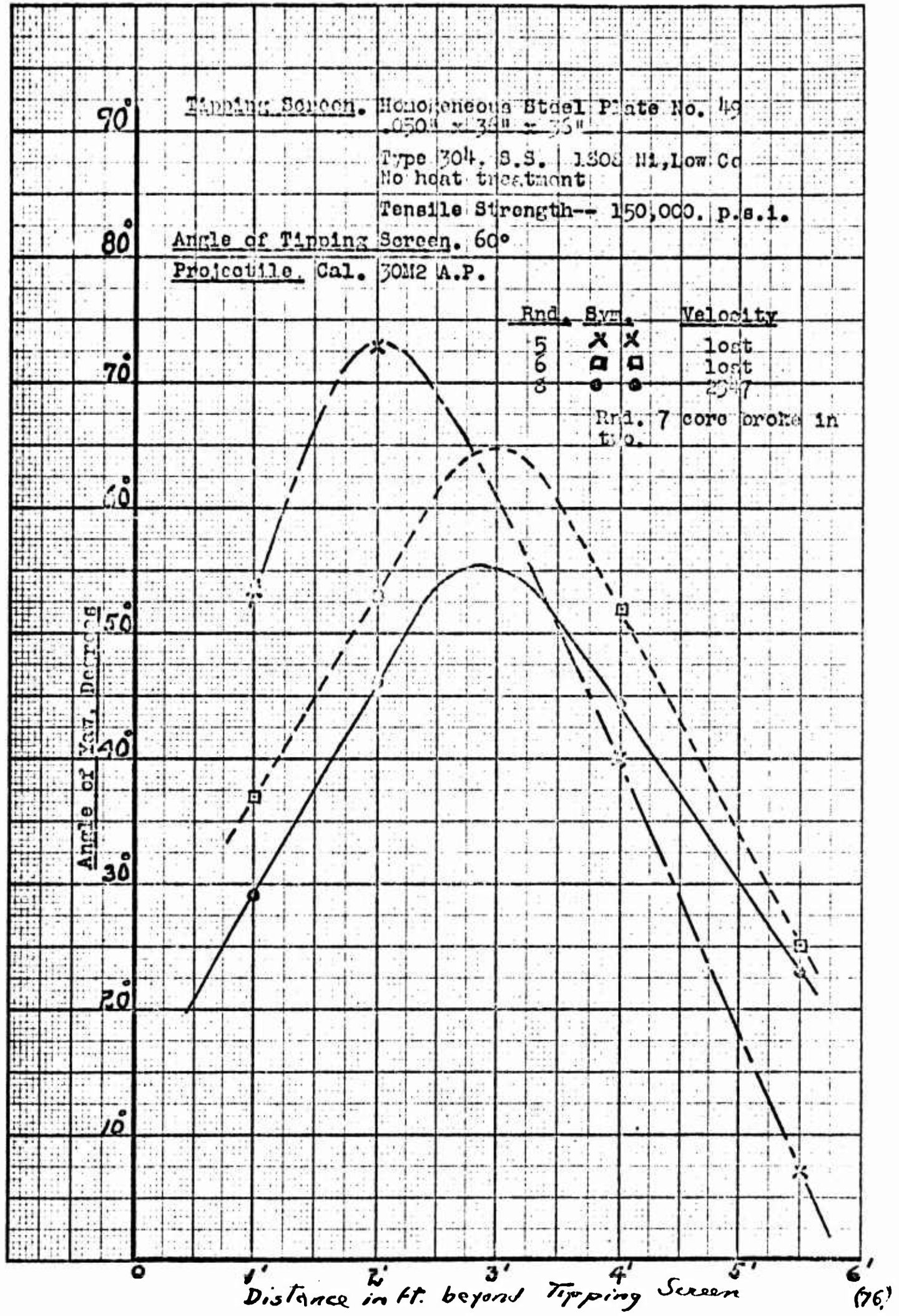
4'

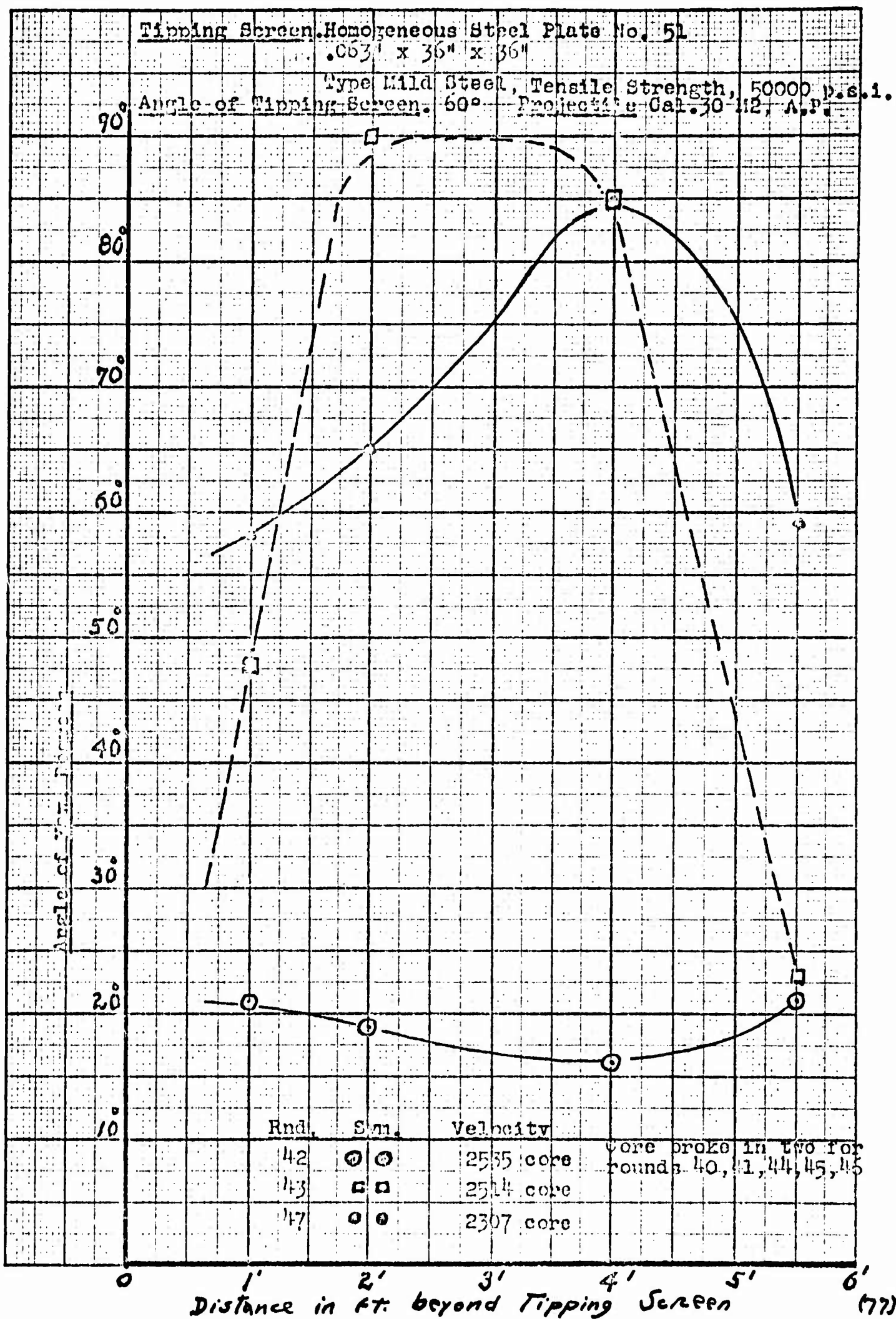
5'

6'

Distance in ft. beyond Tipping Screen

(76)





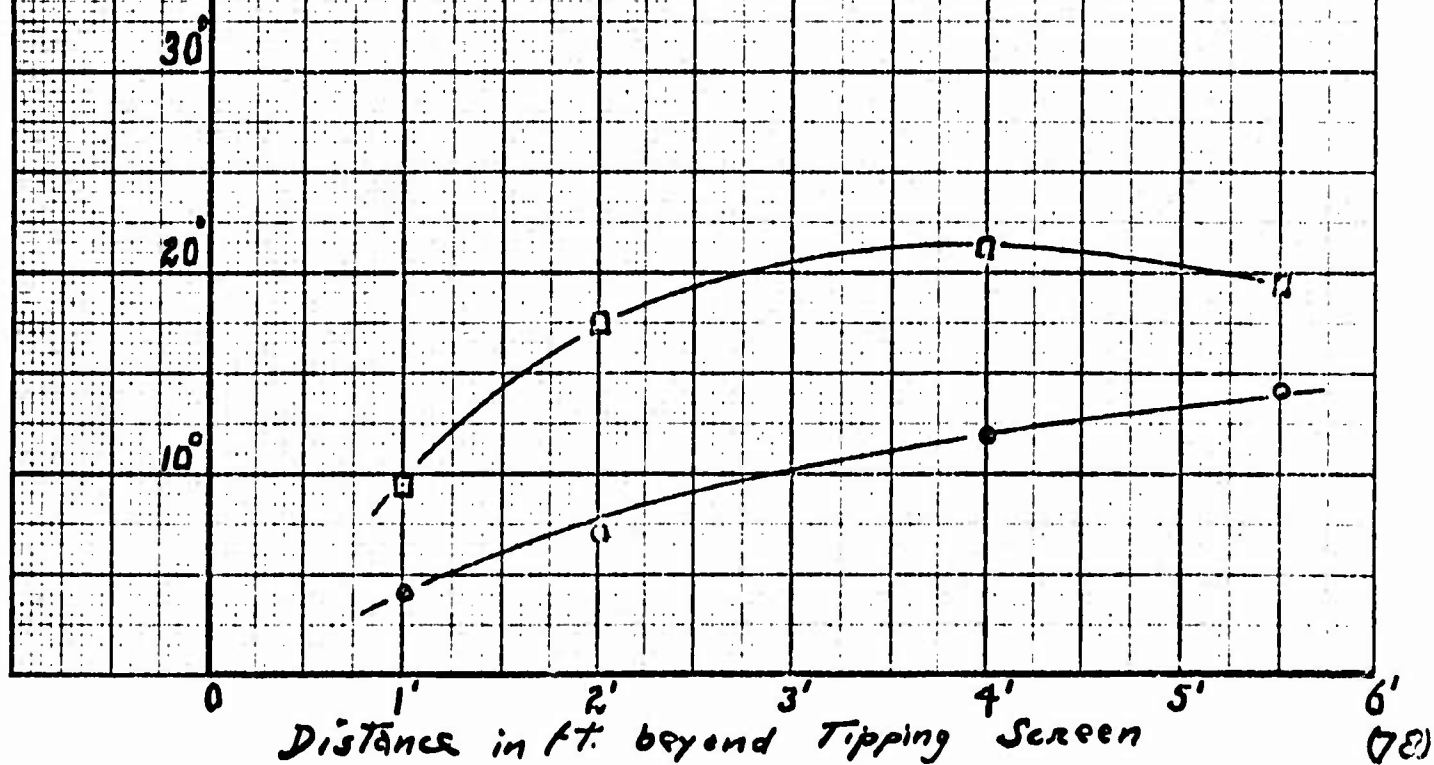
Tipping Screen: Homogeneous Steel Plate No. 52
.025" x 36" x 36"

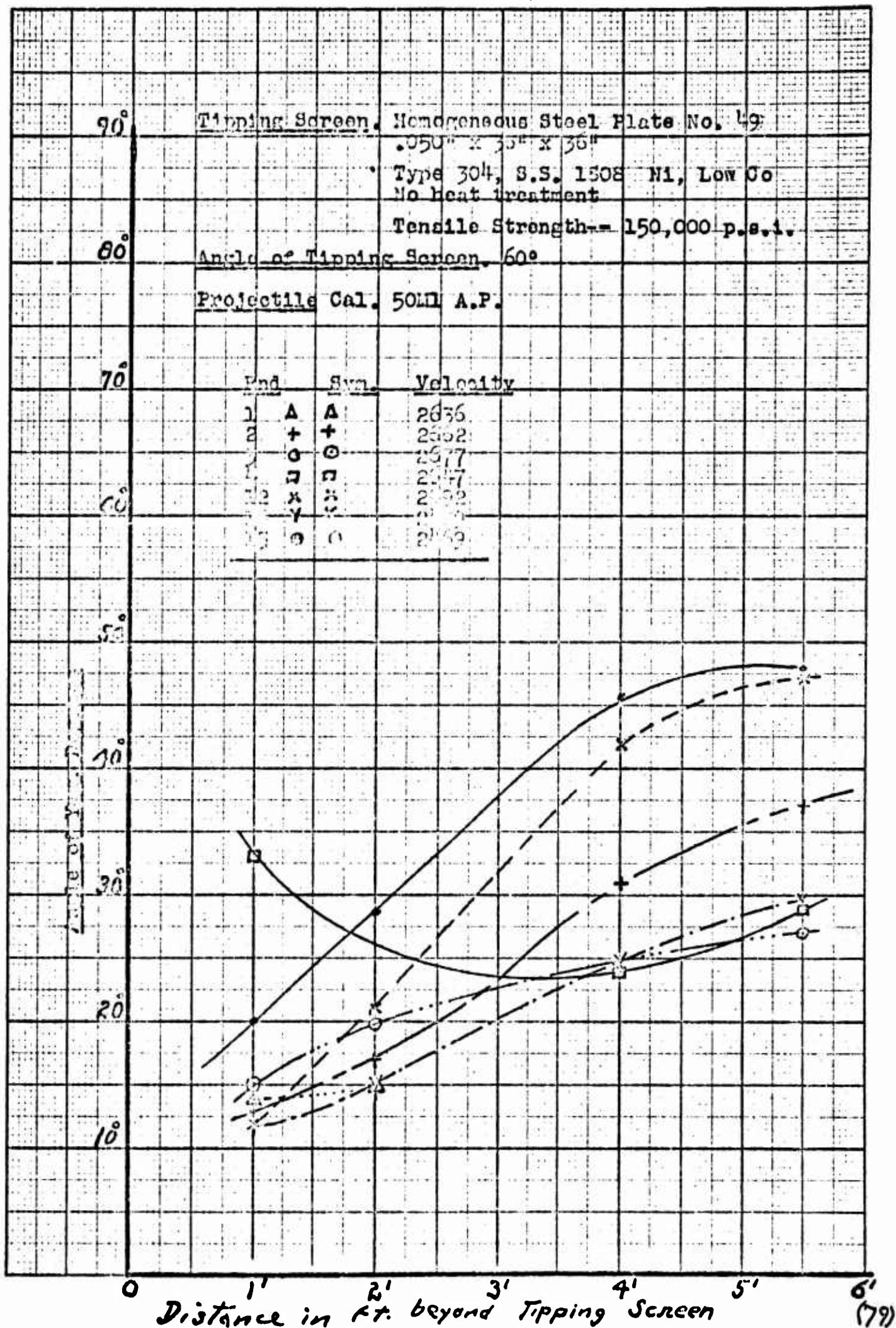
Type 317, 18-8, .40 No, .03 C Max.
Tensile Strength-- 184,000 p.s.i.

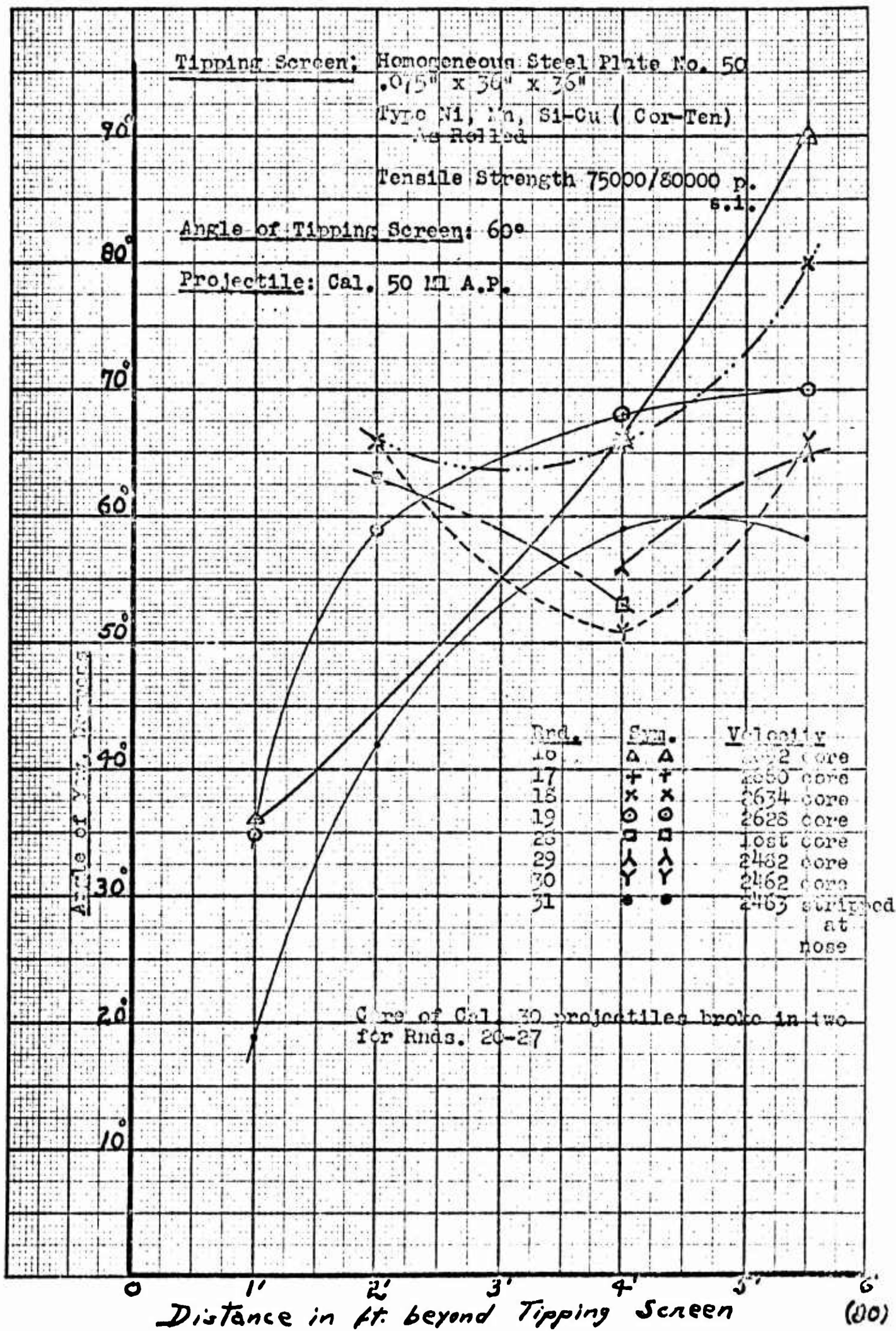
Angle of Tipping Screen: 60°

Projectile: Cal. 30 M2 A.P.

Exp.	Sim.	Velocity
53	□ □	2520
54	• •	2274







90°

Tipping Screen, Homogeneous Steel Plate No. 51
 .063" x 36" x 36"

Type Mild Steel, Tensile Strength 50,000
 p.s.i.

80°

Angle of Tipping Screen, 60°

Projectile, Cal. 50M1 A.P.

70°

Rnd.	Sym.	Velocity
33	• •	2645
34	+ +	2536
35	x x	2537
36	o o	2548
37	□ □	2578
38	Y Y	2586
39	△ △	2570

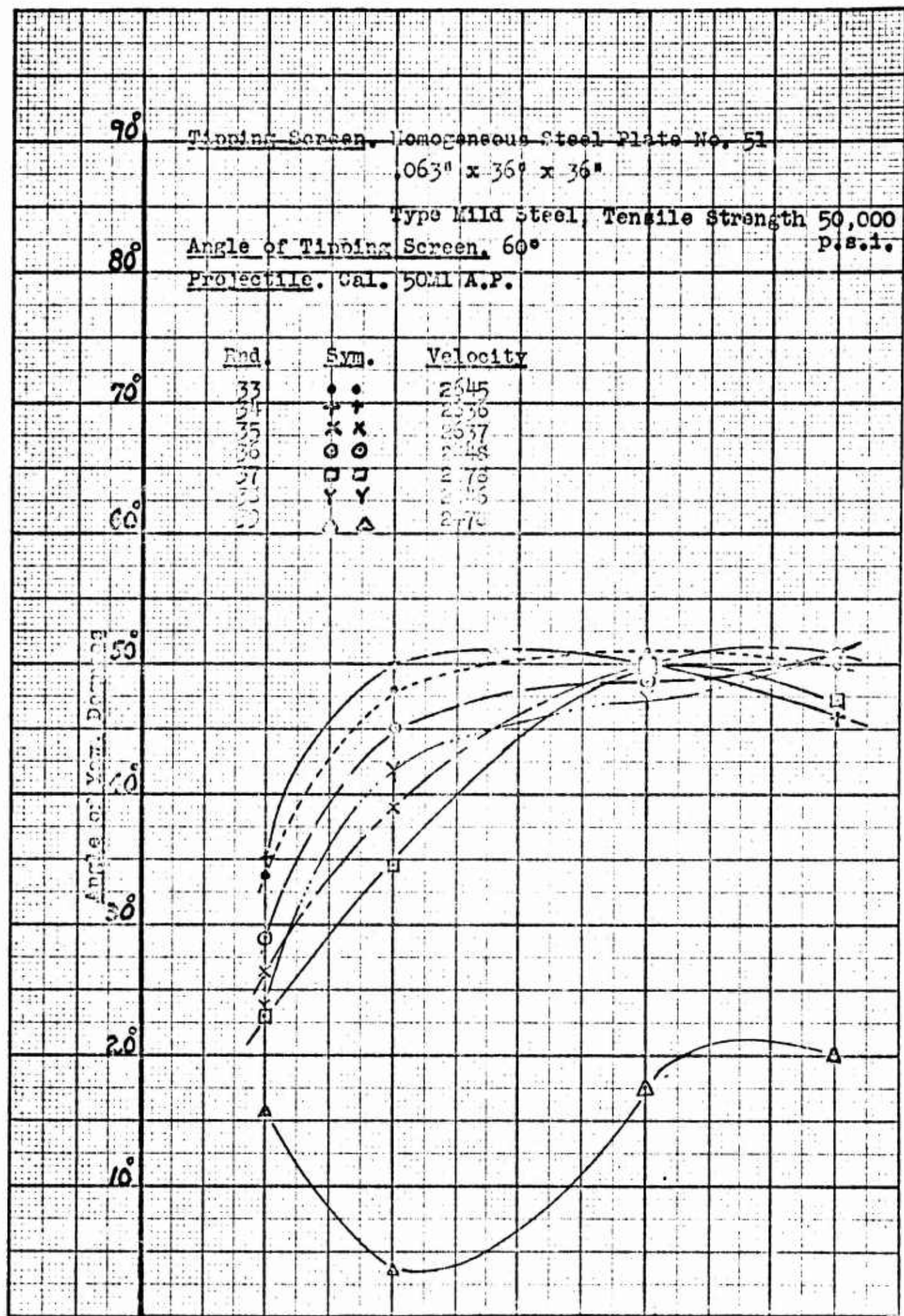
60°

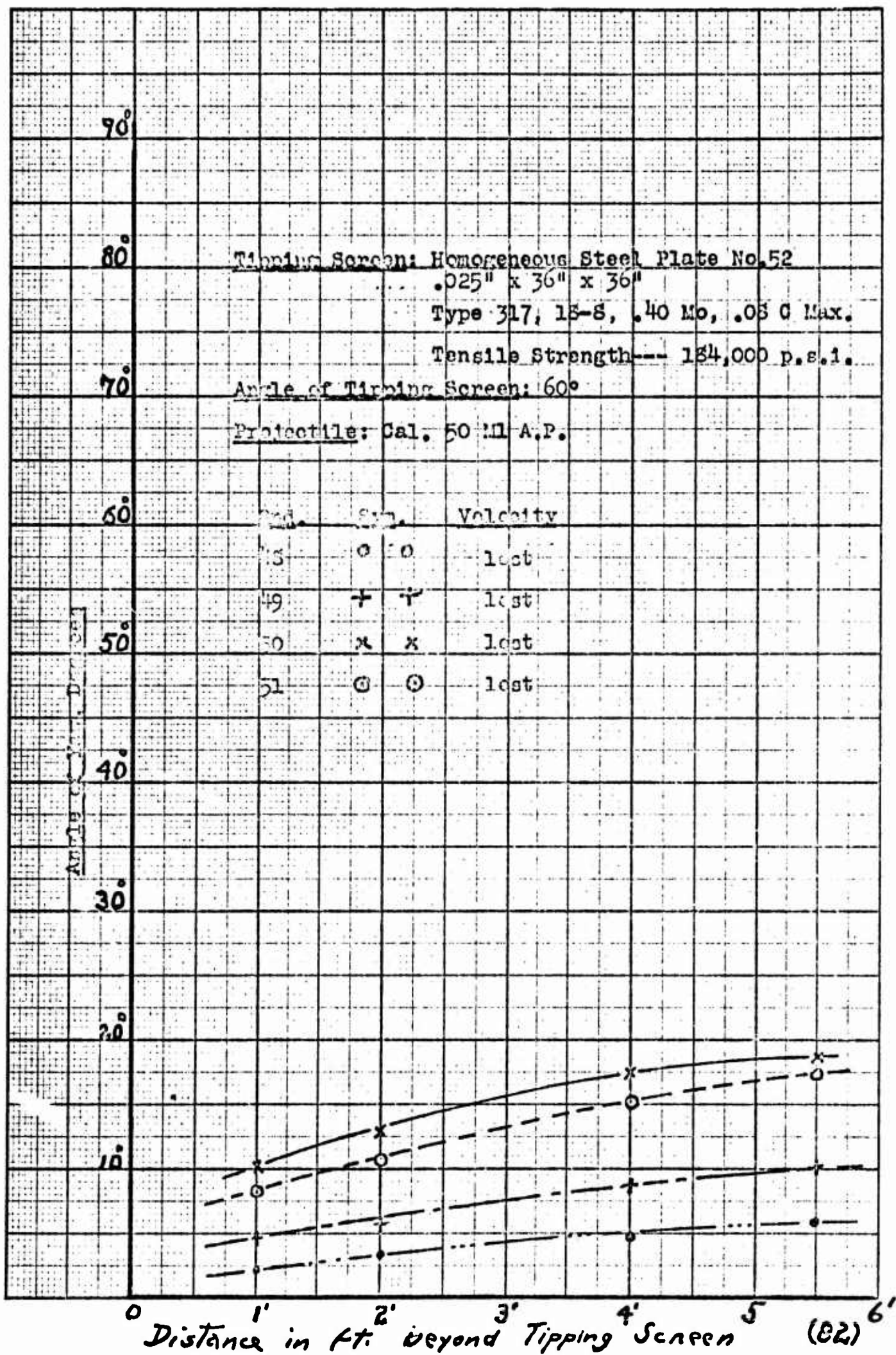
Angle of Motion
 in degrees

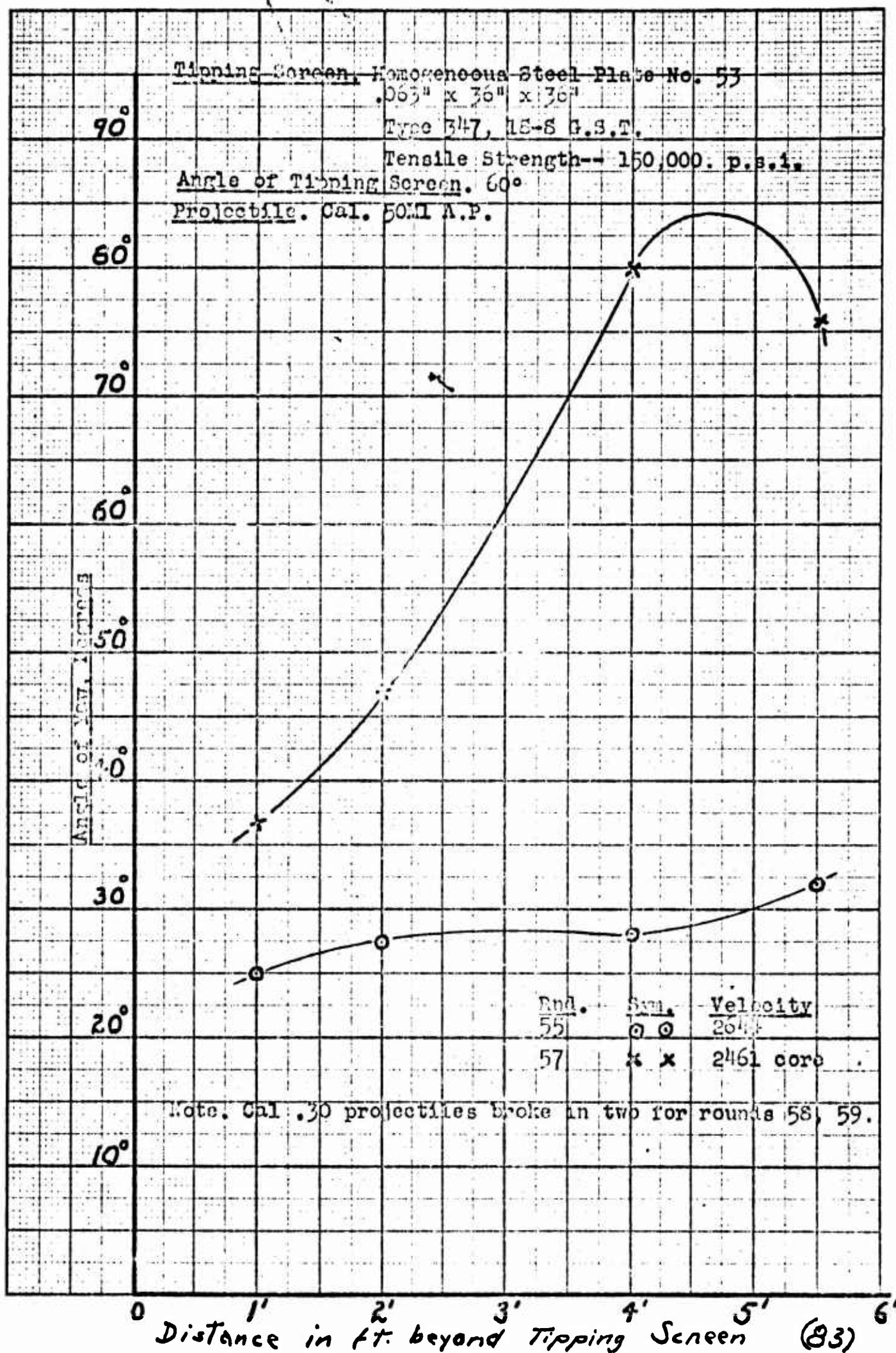
20°

10°

Distance in ft. beyond Tipping Screen (31)







TITLE: Development Tests of Screened Armor Plate

AUTHOR(S): Leeder, J.

ORIGINATING AGENCY: Aberdeen Proving Ground, Ballistic Research Lab., Md.

PUBLISHED BY: (Same)

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ABSTRACT:

The results of development tests of screened armor plate were analyzed. The use of tipping screens produced extraordinary increases in protective efficiency of both face hardened and homogeneous armor plate, particularly for the latter type. Because of the somewhat inappropriate location of the yaw cards, direct correlation of striking yaw and armor plate penetration was not possible. A comparison was made of the ballistic performance of the screened homogeneous armor plate and homogeneous armor plate at high obliquities. In general there were no large differences discernible insofar as the limiting velocities were concerned. A general discussion of some aspects of screened armor plate is given and recommendations are made for an extensive program involving both the armor plate and tipping screen phases of the problem.

DISTRIBUTION: Copies of this report obtainable from Air Documents Division; Attn: MCIDXD

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Air Documents Division, Intelligence Department
Air Materiel Command

AIR TECHNICAL INDEX

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